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EXECUTIVE SUMMARY

River flow is vital for fish populations in the Coorong, Lower Lakes and Murray Mouth (CLLMM) region. Importantly, freshwater inflow affects fishes by influencing: (1) water levels and habitat availability; (2) the salinity regime; (3) connectivity between and within freshwater, estuarine and marine environments; and (4) productivity.

This study aimed to improve understanding of the spatio-temporal patterns in the assemblage structure and population dynamics of fishes in the CLLMM region, with particular emphasis on the effects of drought and increased freshwater inflows. To achieve this, we reviewed research and monitoring in the CLLMM region since 2003/04. Additional quantitative data analyses of several long-term (≥ 6 years) fish monitoring projects were conducted to support this synthesis and assist in the development of level-of-effects tables for fish responses to flows.

During drought (2001–2010), reduced river inflows led to an overall reduction in species diversity, richness and abundance of native fishes. In the Lower Lakes, substantial declines in the range and abundance of threatened, small-bodied species (e.g. Yarra pygmy perch) occurred due to low lake levels and loss of fringing and off-channel habitats. Additionally, the proportional catch of large-bodied, native freshwater fishes was reduced, compared to invasive carp, in the commercial fishery. Conversely, small-bodied estuarine species (e.g. lagoon goby and Tamar River goby) increased in association with increased salinity in the Lower Lakes. Due to loss of connectivity between Lake Alexandrina and the Murray Estuary (no barrage releases from 2007–2010), there was a significant reduction in recruitment and abundance of diadromous species (e.g. congolli and common galaxias) throughout the CLLMM region.

Reduced freshwater inflow to the Murray Estuary and Coorong lagoons led to increased salinities throughout the system, with particularly high levels in the South Lagoon (>100 $g.L^{-1}$), restricting the range of many species. For example, smallmouthed hardyhead, one of the most salt-tolerant species in the world and historically found throughout the Coorong lagoons, was excluded from the South Lagoon during the late drought. At the same time, the distributions of several commercially important estuarine species (e.g. black bream and greenback flounder) were restricted to the vicinity of the Murray Barrages and Murray Mouth. In addition, the recruitment and abundance of a number estuarine species declined, particularly in the North Lagoon, likely

also associated with increased salinities and reduced productivity. Overall, fish assemblage structure in the Murray Estuary was characterised by marine stragglers and marine estuarine opportunists with low species richness and abundance of the functional groups of freshwater, diadromous and estuarine species. Contraction of distributions and low species richness was reflected in the food-web structure of the Coorong lagoons, with shorter food chains due to fewer trophic groups.

In 2010–2015, river flow increased, and fish assemblage structure changed substantially. In the Lower Lakes, there was an overall increase in species richness of small-bodied fishes as fish habitat improved with increased water levels, reduced salinities and improved connectivity. Additionally, large-bodied, freshwater native fishes (bony herring and golden perch) increased proportionally in the commercial fishery catch. Abundances of catadromous species (i.e. congolli and common galaxias) increased due to enhanced recruitment following re-establishment of connectivity between marine, estuarine and freshwater habitats throughout the CLLMM region. However, threatened, small-bodied freshwater fishes remained in low numbers in Lake Alexandrina, and were absent in Lake Albert, indicating limited population recovery.

In the Murray Estuary and Coorong lagoons, increased freshwater inflows and reduced salinities resulted in southward range extensions of several species, including black bream, yelloweye mullet and greenback flounder. Several species were recorded in the South Lagoon for the first time since 2001/02. The increased number of trophic groups (e.g. piscivorous fish) in the Coorong lagoons, due to range extensions, resulted in longer food chains and increased food-web complexity. Higher inflows, reduced salinities and increased productivity led to enhanced recruitment and abundance of many species, particularly small-bodied estuarine fishes (e.g. Tamar River goby, sandy sprat, smallmouthed hardyhead). Higher abundances, in particular for sandy sprat, supported larger predators (e.g. mulloway). Generally, post-drought changes in the fish assemblage were driven by increases in species richness and abundances of freshwater, estuarine resident, marine estuarine opportunist and diadromous species.

With reduced river inflows, from 2013–2015 fish assemblages in the CLLMM have transitioned towards those characteristic of low flows. Flow management implications for fishes in this region are provided, along with future research needs to improve understanding of fish-flow relationships and population ecology.

1 INTRODUCTION

The Murray Estuary, Coorong lagoons and freshwater Lower Lakes lie at the terminus of Australia's longest river system, the Murray–Darling (Figure 1). The Coorong, Lower Lakes (lakes Alexandrina and Albert) and Murray Mouth (CLLMM) region has been listed as a Wetland of International Importance under the Ramsar Convention since 1985, and represents one of six 'icon sites' identified across the Murray-Darling Basin (MDB) as part of *The Living Murray* (TLM) program (MDBC 2006). The region is characterised by a diverse fish assemblage, comprising a range of life-history strategies, including freshwater (e.g. golden perch *Macquaria ambigua*, southern pygmy perch *Nannoperca australis*), diadromous (e.g. congolli *Pseudaphritis urvillii*), estuarine (smallmouthed hardyhead *Atherinosoma microstoma*) and marine (e.g. mulloway *Argyrosomus japonicus*) species (Zampatti *et al.* 2010; Wedderburn *et al.* 2014a; 2016; Ye *et al.* 2015a, Wedderburn *et al.* 2016). Freshwater species predominate in the Lower Lakes, whilst the Murray Estuary and Coorong lagoons provide breeding, nursery and feeding grounds for species representing a range of life-history strategies and a migration pathway for diadromous species.

The native fishes of the CLLMM have a wide range of ecological, economic and social values, including: (1) representing key components of biodiversity at site and national scales (four species listed under the *Environment Protection and Biodiversity Conservation Act 1999, EPBC Act 1999*); (2) representing key elements of food-webs and ecosystem function; (3) providing indicators of ecosystem health; (4) supporting the Lakes and Coorong commercial and recreational fisheries; and (5) representing important cultural values for the Ngarrindjeri people.

During 2001–2010, the CLLMM region was severely impacted by an extended drought (van Dijk *et al.* 2013) with reduced freshwater inflows from the River Murray. During this period water levels in the Lower Lakes receded to ~1 m below sea level, leading to the desiccation of fringing and off-channel habitats (e.g. wetlands and drainage channels) and increased salinity, with a corresponding decline in threatened native fish populations (Wedderburn *et al.* 2014a). In the Murray Estuary and Coorong lagoons, the lack of freshwater inflows, increased salinities and reduced connectivity between marine, estuarine and freshwater habitats caused a fundamental change in fish assemblage structure and a general decline in fish abundance, distribution and recruitment (Zampatti *et al.* 2010; Ye *et al.* 2015a, Wedderburn *et al.* 2016).

The drought was broken in late 2010 by the largest overbank flow since 1993, peaking at 93,000 $ML.day^{-1}$ and causing extensive flooding in the lower River Murray and a substantial increase in freshwater inflows to the CLLMM region. In 2010, the CLLMM Recovery Program was initiated by the Department of Environment, Water and Natural Resources (DEWNR), funded by the Council of Australian Governments, with the objective of managing the region to provide a healthy, productive and resilient wetland system that meets international obligations under the Ramsar Convention (DEWNR 2016). The Program included addressing risks to threatened and endangered fish species listed under the *EPBC Act 1999*. Ecological restoration and facilitation of post-drought recovery of fish populations were important components of the Program (DEWNR 2016).

The aim of this study was to improve understanding of the spatio-temporal patterns in fish assemblage structure, and population dynamics in the CLLMM region, particularly regarding the impacts of drought on fishes and their response/recovery following increased freshwater inflows. To achieve this, we reviewed and synthesised information from published reports and peer-reviewed literature on fish ecology, including trophic relationships, from research and monitoring in the CLLMM Region since 2003/04, which included drought and high flow periods (Appendix A). Additional qualitative data analyses of several long-term fish monitoring projects, requested by DEWNR, were conducted to support this synthesis and produce simple level-of-effects tables for flow-related patterns in fish populations (Appendix B).

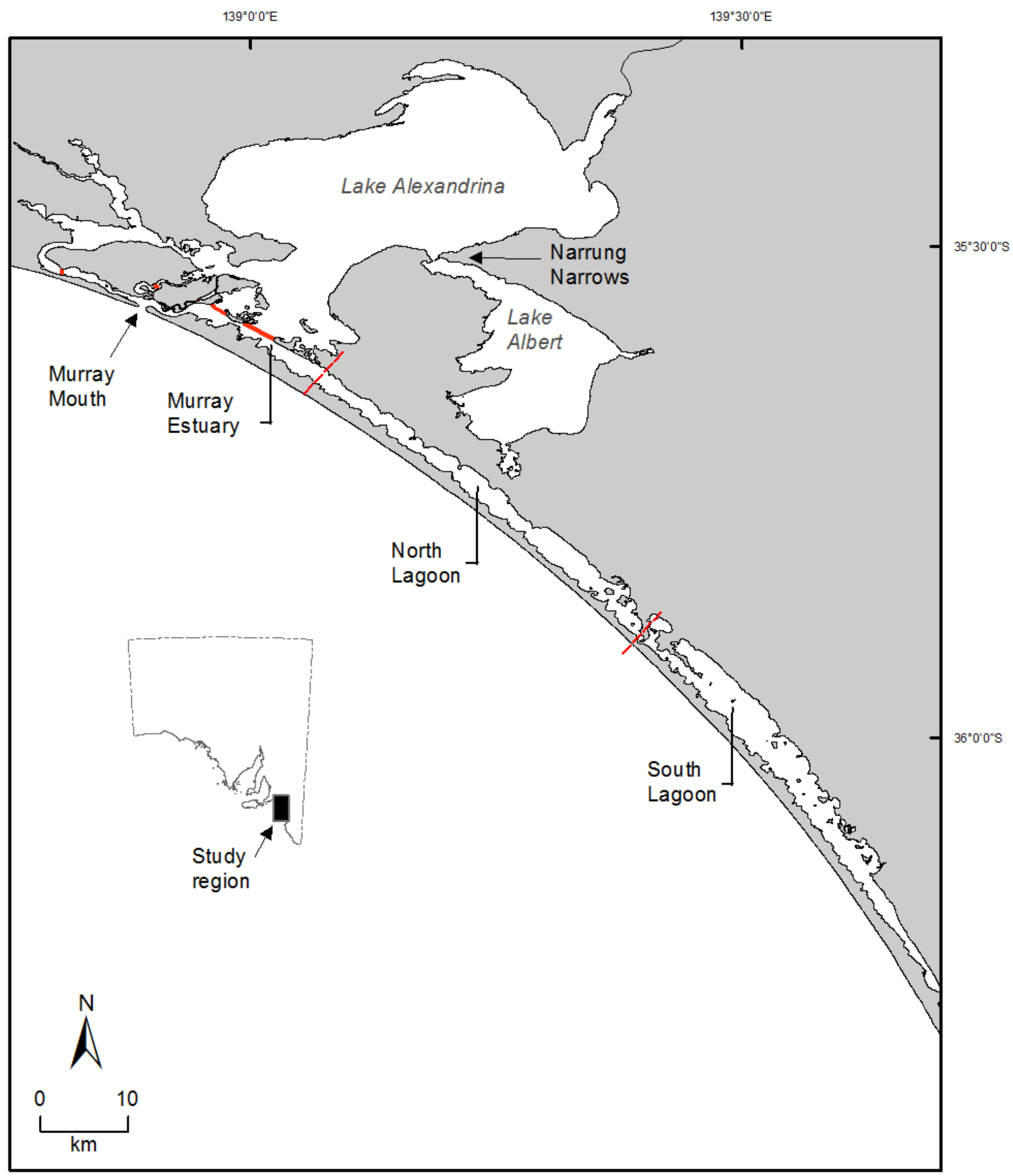

Figure 1. The Coorong, Lower Lakes and Murray Mouth (CLLMM) in South Australia. In the insert, arrow shows location of the CLLMM in South Australia. Dotted lines represent the five barrages and dashed lines show approximate boundaries between the three subregions of the Coorong: the Murray Estuary, North Lagoon and South Lagoon.

2 FISH MONITORING SYNTHESIS

2.1 Flow, salinity and water levels

Freshwater inflow from the River Murray is a key driver of ecological processes and biological responses in the CLLMM region. Under natural conditions, annual inflow to the region was variable, but averaged 12,333 GL.year^{-1} (CSIRO 2008). Due to the impact of river regulation and water extraction, average annual inflows have declined by 61% to 4,733 GL.year^{-1} since the 1930s (CSIRO 2008). Over the last 15 years, which encompasses the temporal scope of fish research and monitoring projects synthesised herein, the CLLMM region experienced extreme hydrological variability, incorporating a protracted drought from 2001–2010, followed by high flows in 2010/11, and subsequent decreasing discharge until 2015.

During the drought, inflow to the Murray Estuary and Coorong lagoons was predominantly <300 GL.year^{-1} (Figure 2) with no inflows in 2002/03, and from 2007/08 to 2009/10. The drought was broken in late 2010 by high freshwater inflows. Freshwater discharge to the system was above the average annual post-regulation flow in 2010/11, 2011/12 and 2012/13, with barrage releases of 12,498 GL, 8,795 GL and 5,177 GL, respectively (Figure 2). In subsequent years, annual barrage discharge reduced to below the post-regulation average. Over the past years (2000/01–2014/15), the southern end of the South Lagoon also received small volumes of fresh/brackish water (mean 13.9 GL y^{-1}) from a network of drains (the Upper South East Drainage Scheme) through Salt Creek.

The River Murray flow and barrage discharge determine water levels and physico-chemical character of the Lower Lakes, Murray Estuary and Coorong lagoons. With persistent drought, water levels in the Lower Lakes declined drastically from 2007–2009, reaching a low of -1.0 m Australian Height Datum (AHD) in April 2009 (Figure 3). Lake levels remained below sea level from April 2007 until August 2010. This resulted in the desiccation of lake-fringing and off-channel wetlands (critical habitat for small-bodied threatened fish), increased salinities, and an increased threat of low soil pH (Mosley *et al.* 2014). There was also a reduction (or loss) of connectivity between lakes Alexandrina and Albert, and among the Lower Lakes, Murray Estuary, Coorong lagoons and marine environments. Low freshwater inflows from the River Murray also led to reduced nutrients and turbidity in the Lower Lakes (Mosley *et al.* 2012; Oliver *et al.* 2015).

Following the flood in 2010/11, water levels in Lake Alexandrina quickly recovered to those observed pre-drought and have remained there to 2016 (Figure 3). From 2011/12, salinity declined, nutrient input increased, and the connectivity of habitats was restored throughout the Lower Lakes (LeBlanc *et al.* 2012). For Lake Albert, which is a terminal lake with inflows limited by the Narrung Narrows (Figure 1), recovery of environmental conditions (e.g. salinity, turbidity), microalgal communities, and fishery catch assemblages have occurred over a longer period than in Lake Alexandrina (Oliver *et al.* 2014; 2015; Ferguson and Ye 2016) with little indication to date of having returned to the pre-drought state.

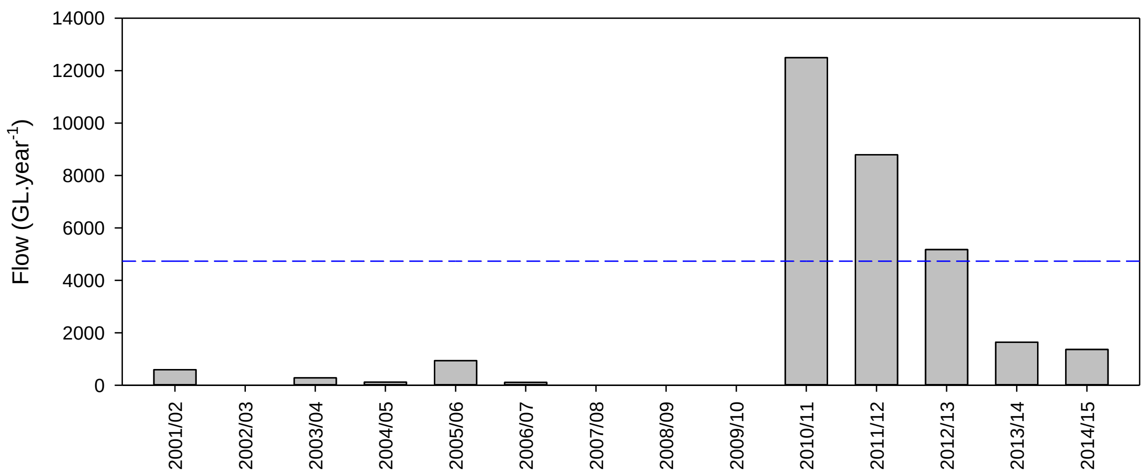

Figure 2. Annual freshwater flows over the Murray barrages from July 2001 to June 2015 (Data sources: MDBA). Dotted line represents average annual flow under regulated conditions.

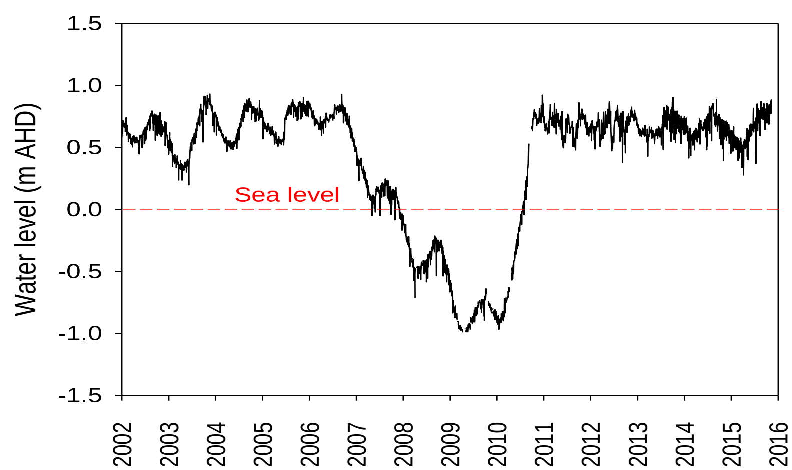

Figure 3. Daily measurements of water level (mAHD) in Lake Alexandrina from January 2002 to November 2015. (Data sources: Surface Water Connect Data)

In the Murray Estuary and Coorong lagoons, salinities are largely influenced by discharge from the Murray barrages and interplay with tides. The hydrology and geomorphology of the Coorong, however, also produces a salinity gradient, with salinity increasing from the Murray Estuary southeast to the South Lagoon, irrespective of freshwater inflow (Geddes 1987). During the drought, lack of freshwater inflows led to a general increase in salinity throughout the entire Murray Estuary and Coorong lagoons and contraction, and ultimately absence, of a salinity gradient from brackish to marine. During most years of the drought, marine salinities (36 psu) occurred in the Murray Estuary and hyper-marine salinities (>3 x seawater, ~130 psu) were observed in the North and South lagoons. Connectivity between estuarine and freshwater habitats was substantially reduced or lost (e.g. 2007–early 2010), and dredging at the Murray Mouth was required for eight years (2002–2010) to maintain estuarine–marine connectivity.

Following flooding in late 2010, salinity was substantially reduced throughout the system with the salinity gradient (freshwater–brackish–marine) restored in the Murray Estuary and northern part of the North Lagoon and salinity reduced to <100 psu in the South Lagoon. Importantly, connectivity was re-established between freshwater, estuarine and marine environments and has persisted since late 2010. Owing to recent reduced flows, dredging of the Murray Mouth recommenced in January 2015 (DEWNR 2015).

2.2 Functional groups of fishes

Fishes representing a diverse range of life-history strategies have been recorded in the CLLMM region. To conceptualise our understanding of fish response to inflows to the CLLMM region, fish species were aggregated into one of the following eight functional groups adapted from the classification scheme of Potter *et al.* (2015): freshwater native; freshwater threatened; freshwater exotic; diadromous (catadromous/ anadromous); estuarine resident; estuarine/marine; marine estuarine opportunist, and marine straggler (Table 1; SARDI unpublished data).

Table 1. Functional groups of fishes.

Symbol	Functional group	Life-history and habitat association
	Freshwater native	Freshwater obligate native species e.g. bony herring, golden perch
	Freshwater threatened	Freshwater obligate species listed as Protected under the SA *Fisheries Act* 2007 or listed under the *EPBC Act 1999* e.g. Murray hardyhead, southern pygmy perch, Yarra pygmy perch
	Freshwater exotic	Freshwater obligate alien species e.g. common carp, goldfish, redfin perch, eastern gambusia
	Diadromous	Catadromous – spend their trophic life in freshwater and subsequently migrate out to sea to spawn e.g. congolli (obligate), common galaxias (facultative) Anadromous – most growth occurs at sea before migration to rivers to spawn e.g. pouched lamprey (obligate), shortheaded lamprey (obligate)
	Estuarine resident	Found primarily in estuaries and complete life cycle within estuaries e.g. black bream, smallmouthed hardyhead
	Estuarine/marine	Represented by both estuarine and marine populations e.g. yelloweye mullet
	Marine estuarine opportunist	Regularly enter estuaries in substantial numbers but also use coastal marine habitat as alternative nursery areas e.g. mulloway, greenback flounder, Australian salmon, sandy sprat
	Marine straggler	Spawn at sea. Enter estuaries sporadically in low numbers and are most common in the lower reaches where salinities typically do not decline far below ~35 psu. e.g. little weed whiting, western striped grunter

2.3 Fish response to flows

Flow affects riverine fish populations – *directly*, by influencing critical life-history processes including spawning, recruitment, growth, movement and migration (Junk *et al.* 1989; Humphries *et al.* 1999; King *et al.* 2009a), and *indirectly*, by influencing ecosystem productivity, connectivity and hydraulic conditions, as well as habitat availability and selectivity (Nestler *et al.* 2012). For the CLLMM region, fish research and monitoring over the last decade (Appendix A), incorporating a period of hydrological extremes (drought – high flow), highlights the importance of the flow regime and river discharge for freshwater and estuarine fish populations. Specifically, freshwater inflows influence fishes in this region through the following critical factors: (1) water levels in the Lower Lakes; (2) connectivity within, and between, lake, estuarine and marine environments; (3) salinity; and (4) productivity by transporting carbon, nutrients and microbiota from upstream. Conceptual diagrams presented in Figures 4 and 5 demonstrate flow-related trends in environmental factors that impact on the quality of fish habitat and observed population responses of fish functional groups in the Lower Lakes, Murray Estuary and Coorong lagoons for drought and post-drought scenarios, respectively.

Lower Lakes

Fish assemblage structure in the Lower Lakes changed significantly between drought and flood (Appendix B). During the drought, there was a general reduction in species diversity and richness (Figure 4). For small-bodied fishes in the Lower Lakes, this reduction in complexity of the assemblage likely resulted from: (1) loss of freshwater habitats due to low lake levels and subsequent salinisation and drying; (2) loss of connectivity among lake fringing habitats; and (3) disconnection of the Murray Estuary from the Lake Alexandrina. Declines in the ranges and abundances of threatened, small-bodied species, namely Murray hardyhead (*Craterocephalus fluviatilis*), Yarra pygmy perch (*Nannoperca obscura*) and southern pygmy perch, were evident from several fish monitoring projects conducted throughout the drought period (Bice *et al.* 2008; Wedderburn *et al.* 2012). These declines were primarily due to reduction in the area of fringing and off-channel habitat through desiccation, salinisation and loss of freshwater vegetation (Wedderburn and Hillyard 2010; Wedderburn *et al.* 2014a). Additionally, loss of connectivity between Lake Alexandrina and the Murray Estuary resulted in reduced abundances of diadromous fishes (e.g. congolli, catadromous). Concurrently, in association with increasing salinity in the Lower Lakes, the abundance of estuarine species (e.g. lagoon goby *Tasmanogobius lasti* and Tamar River goby *Afurcagobius tamarensis*) increased (Wedderburn *et al.* 2012).

During drought, freshwater exotic fishes (primarily common carp, *Cyprinus carpio*) comprised more than 50% of commercial fishery catches in Lake Alexandrina (Ferguson and Ye 2016). Common carp has generalist habitat requirements and, in addition to strong recruitment in high-flow years (Bice *et al.* 2014), is also capable of spawning and recruiting in low flow years. In contrast, some freshwater native species that are important to the fishery in the Lower Lakes (e.g. golden perch) undergo enhanced recruitment in years of high freshwater flow in the River Murray (Ye 2005; Zampatti and Leigh 2013; Zampatti *et al.* 2015).

Increased freshwater inflows after drought (Figure 5) resulted in an overall increase in species richness of small-bodied fishes in the Lower Lakes (Appendix B), although this was delayed in

Lake Albert potentially due to limited connectivity via the Narrung Narrows. Long-term (25-year) fisheries catches in the Lower Lakes showed a decline in the number of large-bodied, freshwater species prior to 2005 (Ferguson *et al.* 2013), and the number of these species did not increase following freshwater inflows (Appendix B). Assemblage structures from fishery catches, however, reflected higher contributions from freshwater natives and lower contributions from freshwater exotics (Ferguson and Ye 2016). In particular, the proportional increase in freshwater native fishes caught post-drought was due to increased catches of bony herring (*Nematalosa erebi*) and golden perch, likely resulting from enhanced localised recruitment and/or immigration from the River Murray during increased flows (Zampatti and Leigh 2013; Bice *et al*. 2014; Ferguson and Ye 2016).

Abundances of small-bodied estuarine species decreased in the Lower Lakes due to reduced salinity associated with high inflows post 2010, and there were reductions in generalist native freshwater species (Wedderburn *et al.* 2014a). In contrast, the abundances of catadromous species, namely congolli and common galaxias (*Galaxias maculatus*), increased due to re-established connectivity between marine, estuarine and freshwater habitats. Connectivity facilitates migration, an obligate component of diadromous fish life cycles in the CLLMM region (Zampatti *et al.* 2010). Threatened small-bodied freshwater fishes, however, have remained in low numbers in Lake Alexandrina, and continued to be absent in Lake Albert, indicating limited population recovery (Wedderburn and Barnes 2016).

Among the three threatened small-bodied fish species in the CLLMM region, variable patterns of population collapse and post-drought recovery have occurred. Murray hardyhead appears to have been more resilient to the drought than the pygmy perches. Murray hardyhead has a higher salinity tolerance which likely facilitated persistence in low abundances in Lake Alexandrina and in specific refuge areas (high salinity; Wedderburn *et al.* 2008), maintained by environmental water delivery during the drought (Wedderburn *et al.* 2013). This resilience may have contributed to their initial population recovery post-drought, in addition to reintroduction efforts through the Critical Fish Habitat project (Bice *et al.* 2012). Increased inflows, higher lake water levels and improved connectivity likely facilitated the dispersion and population recovery of Murray hardyhead throughout the region.

For the two pygmy perch species, populations were extirpated in the latter stage of drought due to the loss of obligate habitat (Wedderburn *et al.* 2012). The reintroductions of southern pygmy perch (Bice *et al.* 2012) have elicited some recovery, with small, self-sustaining, but isolated populations re-established on Hindmarsh Island (Wyndgate Conservation Park) and Mundoo Island (Wedderburn and Barnes 2014). Despite these reintroductions, the species remains vulnerable to extirpation due to small population size. Conversely, Yarra pygmy perch is likely to be absent from the Lower Lakes or present in extremely low abundance (Wedderburn 2014). This is of concern given the Lower Lakes harboured the only remnant population in the MDB known to be genetically distinct from populations in other catchments of south-eastern Australia (Hammer *et al.* 2010).

Overall, increases in inflows and lake water levels, post-drought, facilitated improvement (e.g. increased recruitment and abundance of diadromous species) to the fish assemblages in the Lower Lakes but assemblage structure has not returned to that of the pre-drought period (e.g. threatened species remain in low abundance and vulnerable to extirpation). The trajectories of fish assemblage structure in Lake Alexandrina suggest that with reduced freshwater inflows from the River Murray in 2014–2015, its fish populations are transitioning towards those that are characteristic of low flow conditions (i.e. similar to 2006/07 when water levels and connectivity were maintained and diadromous species remained abundant).

Murray Estuary and Coorong lagoons

Freshwater inflows into estuaries facilitate a variety of processes, but most importantly for fishes, flow influences salinity regime, habitat connectivity and productivity. Salinity is a primary environmental driver of biotic patterns and processes in estuaries (Kennish 1990); it influences fish distribution, with fish inhabiting areas that have salinities within species-specific preference or tolerance ranges (Potter and Hyndes 1994; McNeil *et al.* 2013). Furthermore, estuarine salinity regimes may influence fish abundance through their effect on reproduction. For example, sperm, eggs and larvae often have specific salinity tolerances (e.g. for black bream, *Acanthopagrus butcheri*, see Newton 1996; Haddy and Pankhurst 2000). In addition, connectivity is critical for the recruitment of diadromous species (e.g. congolli) given their critical life-history attributes (i.e. migration between freshwater, estuarine and marine environments). River inflows also enhance productivity in estuaries, providing additional food resources to fish populations (Bice *et al.* 2016).

During drought (2001–2010), there was a general decrease in fish species richness and abundance in the Murray Estuary and Coorong lagoons (Figure 4; Noell *et al.* 2009; Zampatti *et al.* 2010). The lack of freshwater inflows resulted in elevated salinity throughout the system, with hypermarine conditions (salinity >100 psu) persistent in the South Lagoon for much of this period. Elevated salinities and a decreased salinity gradient reduced the area of suitable habitat and restricted the range of many species. For example, the estuarine resident smallmouthed hardyhead, one of the most salt-tolerant species worldwide and historically found throughout the Coorong, was not present in the South Lagoon during the later stage of the drought (Ye *et al.* 2011b; Wedderburn *et al.* 2016). Meanwhile, the distributions of several commercially important estuarine (e.g. black bream) and marine estuarine opportunist species (e.g. greenback flounder *Rhombosolea tapirina*) were largely restricted to the area near the Murray Barrages and Murray Mouth in the Murray Estuary (Ye *et al.* 2015b; Earl and Ye 2016; SARDI unpublished data). For species such as mulloway, lack of a freshwater plume from the Murray Estuary may have resulted in loss of cues for adults to locate spawning habitat and for larvae/early juveniles to locate protected estuarine habitat, thus negatively impacting on recruitment (Ferguson *et al.* 2008).

During 2007–2010, absence of freshwater inflows and disconnection (i.e. closed fishways and barrage gates) of the Lower Lakes from the Coorong resulted in recruitment failure and substantial declines in the abundance of catadromous fish (e.g. congolli and common galaxias). Surveys during this period, from which the anadromous short-headed lamprey (*Mordacia mordax*) and pouched lamprey (*Geotria australis*) were undetected (Zampatti *et al.* 2010) provide further evidence of reduced fish migration. Drought led to significant changes in fish assemblage structure in the Murray Estuary and Coorong lagoons. Drought was characterised by reduced abundances of freshwater, estuarine and diadromous species and increased dominance by estuarine/marine species (e.g. yelloweye mullet *Aldrichetta forsteri*) and marine stragglers (Zampatti *et al.* 2010; Ye *et al.* 2015a).

Following resumption of freshwater inflows in 2010, salinities were reduced throughout the Murray Estuary and Coorong lagoons (Figure 5), which led to an overall increase in fish abundance and species diversity (Bice and Zampatti 2015; Ye *et al.* 2015a). Reduced salinities also resulted in southward range extensions for many species and functional groups, including estuarine resident (e.g. Tamar River goby and black bream), marine estuarine opportunist (e.g. sandy sprat *Hyperlophus vittatus* and greenback flounder), estuarine/marine (e.g. yelloweye mullet) and catadromous species (e.g. congolli), with some of these species recorded in the South Lagoon for the first time since 2001 (Livore *et al.* 2013; Ye *et al.* 2015a). Resumption of freshwater inflows also resulted in enhanced recruitment and abundances of a number of estuarine and marine estuarine opportunist species, particularly small-bodied fishes in the North Lagoon, likely attributable to improved water quality and enhanced productivity (Livore *et al.* 2013; Ye *et al.* 2015a).

Restoration of connectivity between the Lake Alexandrina and Murray Estuary and Coorong lagoons contributed to enhanced recruitment and increased distribution and abundance of diadromous species (e.g. congolli and common galaxias) (Bice and Zampatti 2015). Also, in contrast to results of surveys during the drought, pouched lamprey were detected migrating upstream at the Murray Barrages. Significant changes in fish assemblage structure were associated with freshwater inflows post 2010 (Bice and Zampatti 2015). With increased inflows, abundances of freshwater, estuarine resident, marine estuarine opportunist and catadromous species increased, while abundances of estuarine/marine and marine straggler species decreased. Fish population responses to freshwater inflows in the North and South lagoons lagged in comparison to those in the Murray Estuary (Ye *et al.* 2015a). This time lag was likely associated with the delay in flow-mediated salinity change due to spatial distance from the Murray Barrages and several natural constrictions to water flow (Webster 2010).

Overall, increased freshwater inflow to the Murray Estuary and Coorong lagoons facilitated enhanced recruitment, abundance and distribution of estuarine, diadromous and marine estuarine opportunist species. For some species, however, recruitment remains limited (e.g. large-bodied estuarine resident species, black bream; Ferguson *et al.* 2013). Presently, with reduced inflows in 2013–2015, the estuarine fish assemblage is transitioning towards that characteristic of drought/low flows.

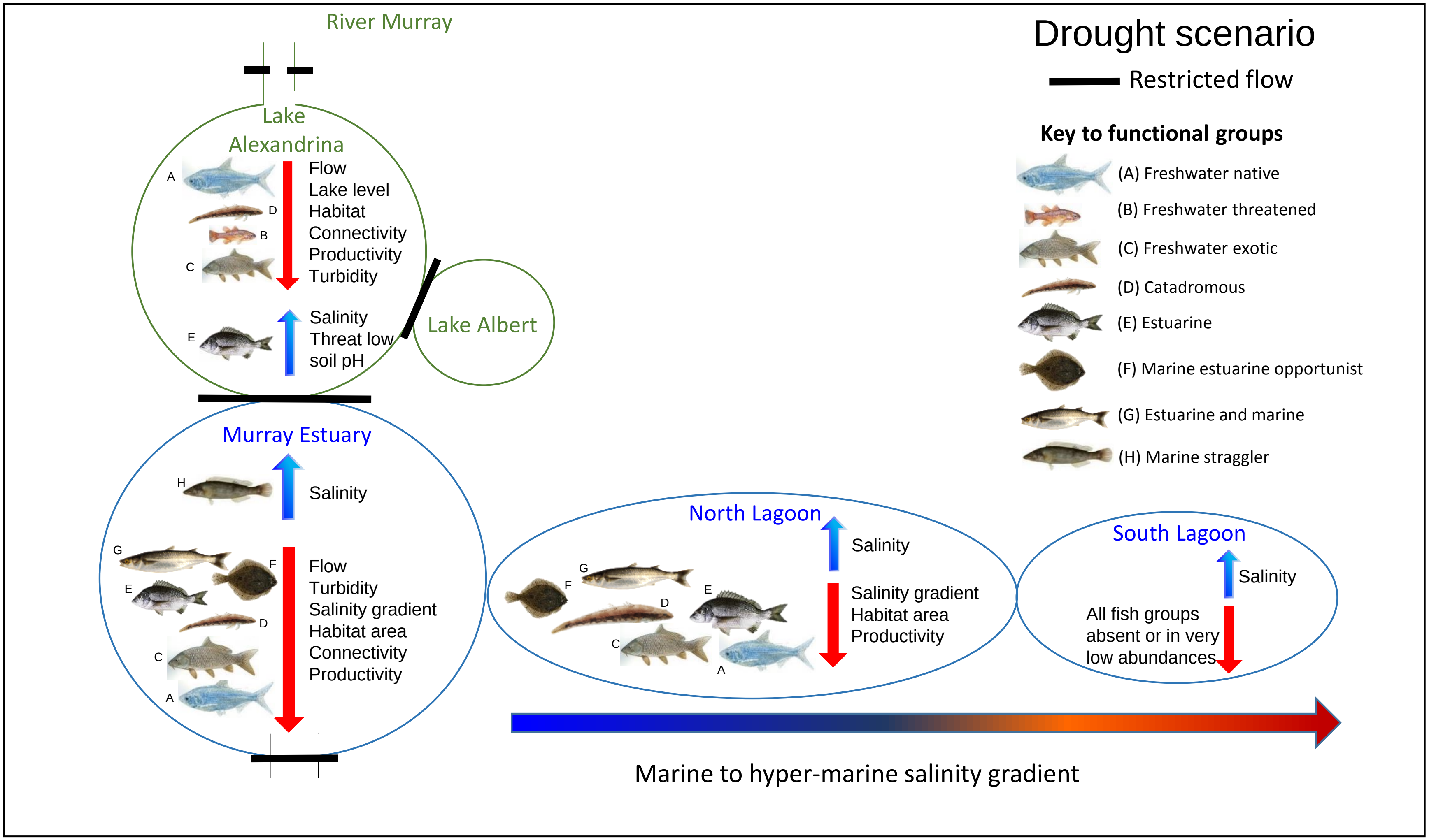

Figure 4. Conceptual diagram showing trends for fish functional groups (left of arrows) and environmental factors that impact on fish habitat quality (right of arrows) in the Lower Lakes, Murray Estuary and Coorong lagoons during drought.

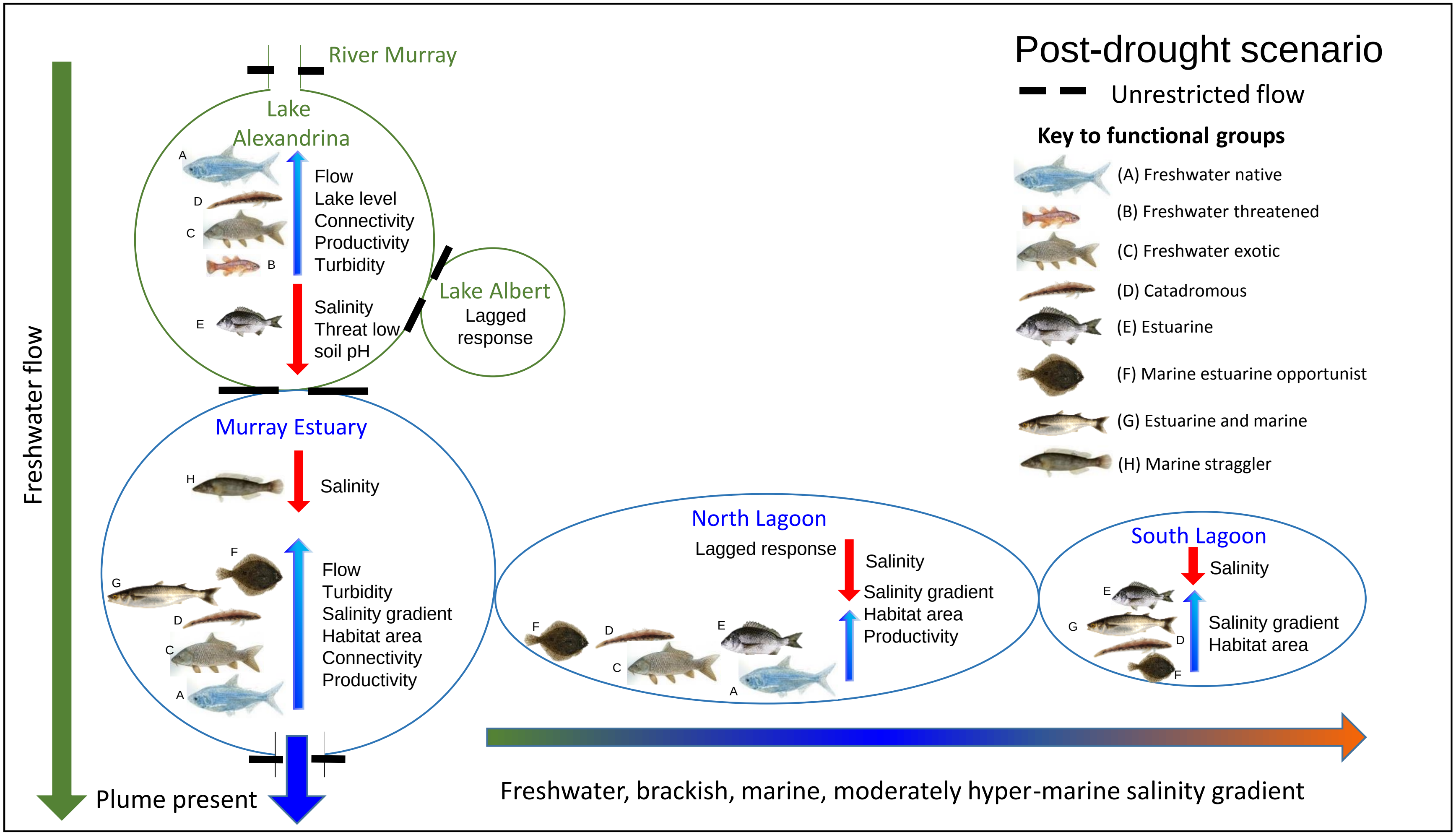

Figure 5. Conceptual diagram showing trends for fish functional groups (left of arrows) and environmental factors that impact on fish habitat quality (right of arrows) in the Lower Lakes, Murray Estuary and Coorong lagoons after post-drought flooding.

2.4 Coorong food-web response to flows

Healthy and resilient food-webs, which are characterised by high levels of productivity and complexity (i.e. longer food chains and greater biotic diversity), are important for maintaining the ecological character of estuarine ecosystems. Ultimately, the function of estuarine food-webs relies on river inflows, which facilitate the transport of organic matter and nutrients to estuaries to stimulate productivity (Nedwell *et al.* 1999; Brookes *et al.* 2015). Freshwater inflow also influences salinity gradients, consequently affecting the distribution and abundance of biota (Drinkwater and Frank 1994; Alber 2002; Kimmerer 2002), which impacts on food-web structure (e.g. trophic pathways). Over the last decade, stable isotope investigations in the Murray Estuary and Coorong lagoons have enabled greater understanding of the trophic structure of the food-web (Lamontagne *et al.* 2007; Deegan *et al.* 2010; Giatas and Ye 2015; Bice *et al.* 2016), while gut-content analyses have provided complementary understanding of fish diets and their trophic interactions with prey species (Geddes and Francis 2008; Deegan *et al.* 2010; Earl 2014; Giatas and Ye 2015).

The food-web of the Murray Estuary and Coorong lagoons comprises a diverse biotic community, including the macrophyte *Ruppia tuberosa*, herbivorous and predatory benthic invertebrates, piscivorous and invertebrate-eating fishes, waterbirds and shorebirds (Deegan *et al.* 2010; Giatas and Ye 2016; Figure 6). A review of available literature and development of conceptual food-web models (Giatas and Ye 2016) revealed that food-web structure differed between drought (2003–2010) and post-drought (2010–2013) periods. During drought, low inflows led to high salinities and the contraction of suitable habitat (i.e. <55 psu) for many biota, which was reflected in the food-web structure (Figure 7). Diversity and abundances of benthic macroinvertebrates and fish were highest in the Murray Estuary subregion where salinities were marine (~30–45 psu), but declined into the Coorong lagoons with increasing distance from the Murray Mouth (Figure 7; Noell *et al.* 2009; Dittmann *et al.* 2015). Concurrently, food chain length (i.e. the number of feeding links from the base of the food-web to the top predator) decreased along this gradient (Deegan *et al.* 2010; Giatas and Ye 2016).

In contrast, during the high inflow period post-drought, habitat <55 psu was widespread and extended far into the North Lagoon where fish and macroinvertebrate diversities were high (Figure 7; Livore *et al.* 2013; Dittmann *et al.* 2015), implying enhanced food-web complexity and greater resilience to environmental or biotic disturbances. Similarly, the macroinvertebrate and fish community in the South Lagoon post-drought was represented by multiple taxonomic groups/species (e.g. yelloweye mullet and black bream; chironomids and amphipods), including the highly abundant smallmouthed hardyhead (Figure 7; Dittmann *et al.* 2015; Livore *et al.* 2013; Wedderburn *et al.* 2016).

Greater influence of the pelagic, phytoplankton-based component of the food-web to productivity in the Murray Estuary and North Lagoon during the period post-drought (characterised by high freshwater inflows) was inferred from an increased abundance of zooplankton (Shiel and Aldridge 2011; Shiel and Tan 2013a; 2013b) and higher relative abundances of zooplanktivorous fishes such as sandy sprat and juvenile bony herring (Livore *et al.* 2013). Enhanced pelagic productivity was likely a result of increased zooplankton abundances during high inflows, due to their transportation into the Coorong lagoons from the River Murray and Lower Lakes (Furst *et al.* 2014), and/or in response to increased primary productivity stimulated by allochthonous nutrient/energy input. Indeed, investigation of sandy sprat diet, using gut-content and stable isotope analysis, suggested freshwater zooplankton subsidised the diet of this species in the Murray Estuary following freshwater inflows (Bice *et al.* 2016). This pelagic production subsequently supported higher trophic organisms, with the diet of piscivorous fish and birds likely to have been comprised mostly of sandy sprat and bony herring, i.e. phytoplankton → zooplankton → sandy sprat and juvenile bony herring → Australian salmon (*Arripis truttaceus*), mulloway and piscivorous birds (Figure 6; Giatas and Ye 2015; 2016).

Conversely, benthic production, fuelled by detritus, macrophytes and macroalgae, appeared to play the dominant role in transferring energy to higher trophic levels during the drought (low freshwater inflows), particularly in the Coorong lagoons where the pelagic loop was almost absent, i.e. detritus → benthic invertebrates → smallmouthed hardyhead and yelloweye mullet → mulloway, Australian salmon and piscivorous birds (Figure 6; Giatas and Ye 2016). Higher abundances of zooplankton (Shiel and Aldridge 2011; Shiel and Tan 2013a; 2013b) and other small crustaceans (e.g. amphipods) (Dittmann *et al.* 2015) post-drought could imply that fish recruitment, particularly for large-bodied species, was enhanced by high freshwater inflows. Furthermore, the higher abundance of sandy sprat during high inflows (Bice and Zampatti 2015; Ye *et al.* 2015a) would have contributed to juvenile mulloway diet (Giatas and Ye 2015) and potentially led to enhanced recruitment for that species.

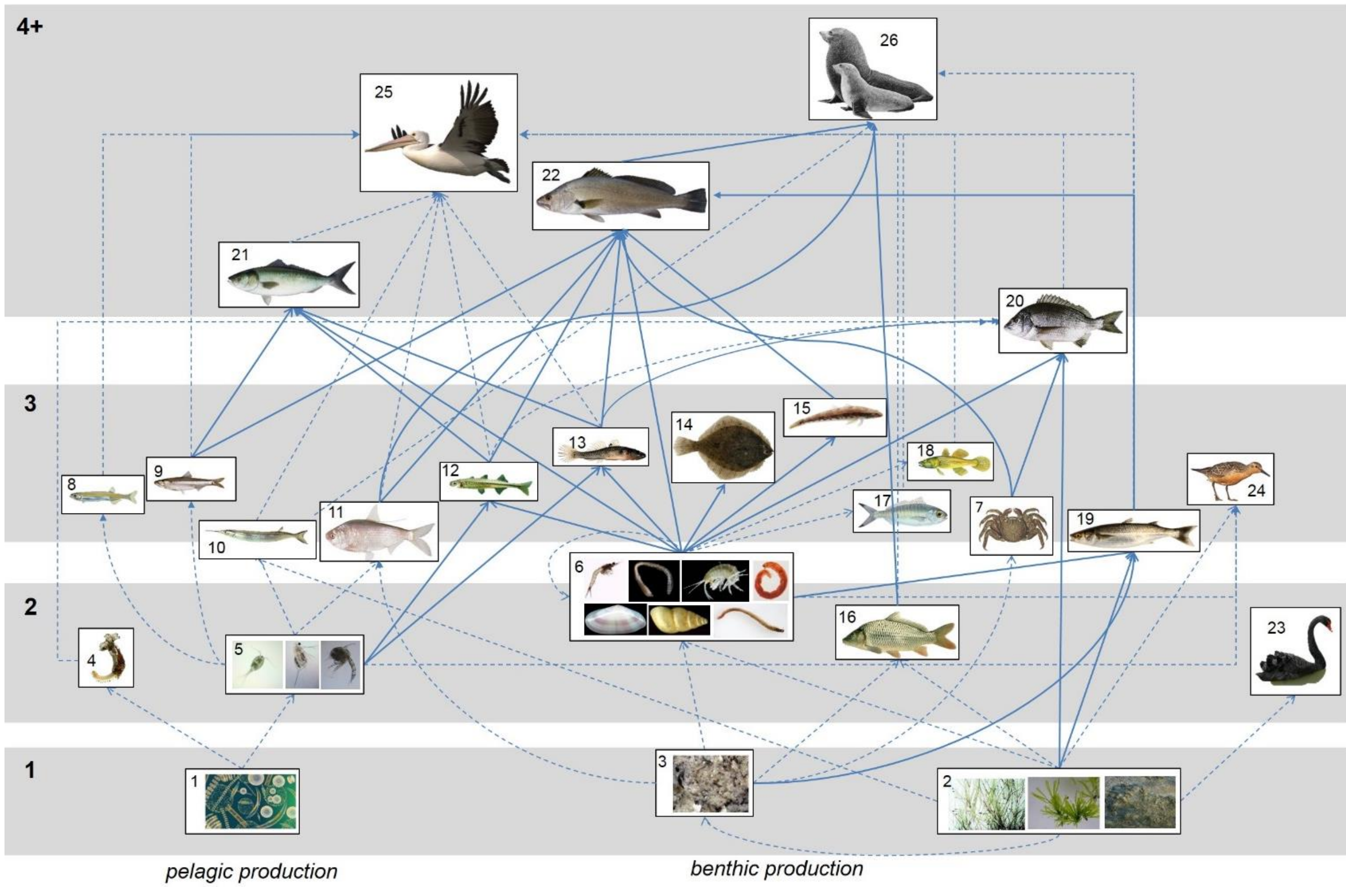

Figure 6. Overall conceptual model of the food-web for the Murray Estuary and Coorong lagoons (Giatas and Ye 2016). Trophic levels 1, 2, 3 and 4+ represent primary producers, primary consumers, secondary consumers and higher-level consumers, respectively. Taxa that occupy intermediate trophic levels (e.g. omnivorous species between level 2 and 3) are situated in zones of overlapping trophic levels. Solid trophic links represent Coorong-based literature, while dotted links are based on literature outside of the Coorong. Biotic groupings are (1) phytoplankton, (2) macrophytes, macroalgae and benthic migroalgae, (3) detritus, (4) *Ficopomatus enigmaticus*, (5) zooplankton, (6) benthic invertebrates e.g. amphipods, polychaetes, insect larvae, shrimp, small crabs, bivalves and gastropods, (7) *Paragrapsus gaimardii*, (8) Australian smelt, (9) sandy sprat, (10) river garfish, (11) bony herring, (12) smallmouthed hardyhead, (13) gobies, (14) greenback flounder, (15) congolli, 16) carp, (17) Australian herring, (18) flathead gudgeon, (19) yelloweye mullet, (20) black bream, (21) Australian salmon, (22) mulloway, 23) herbivorous waterbirds, (24) shorebirds, (25) piscivorous birds and (26) long-nosed fur seal. Refer to Giatas and Ye (2016) for model guidelines.

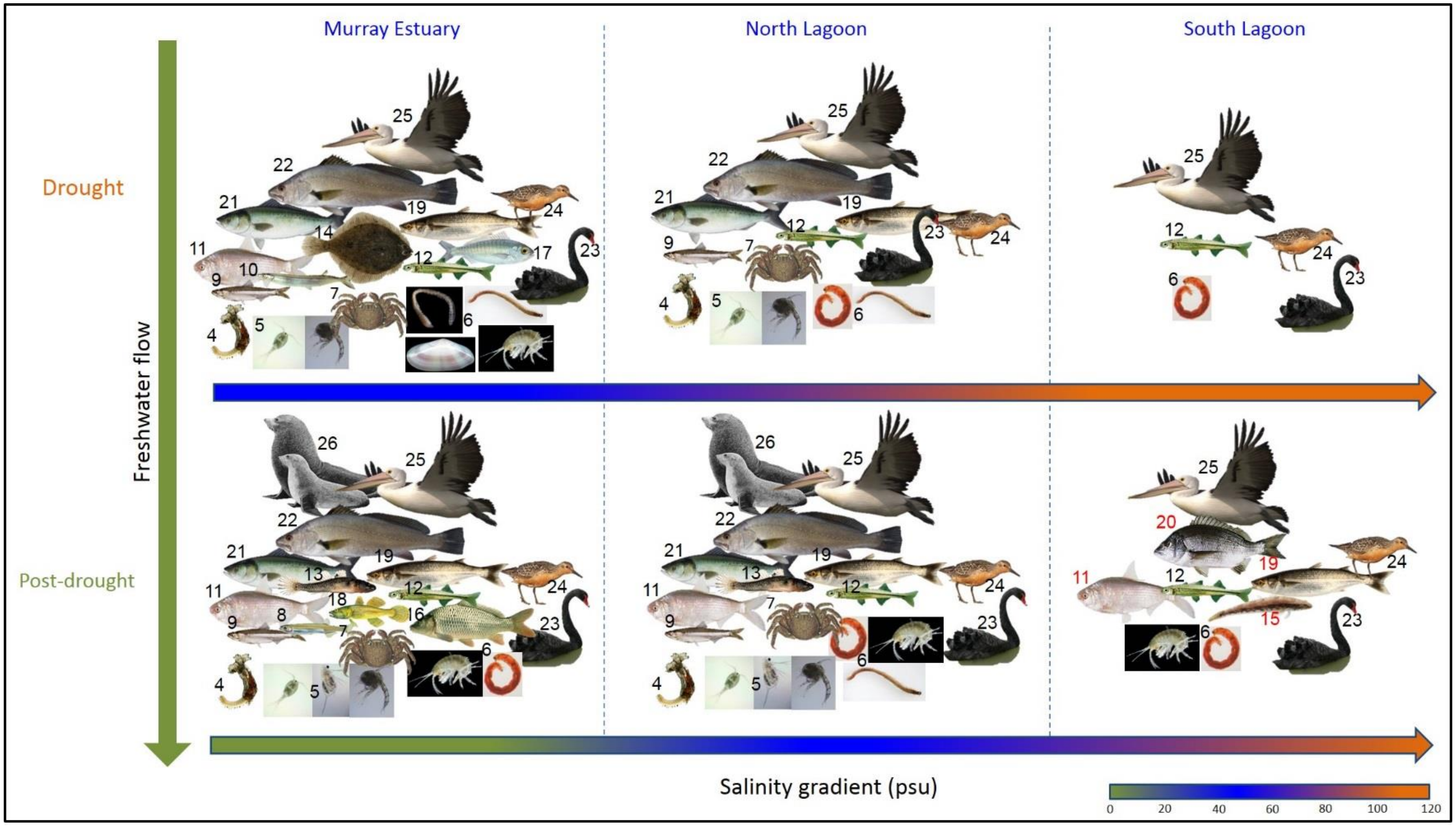

Figure 7. Abundant fish species (i.e. ≥1% total numerical abundance from seine and gill net catches for small-bodied and large-bodied species, respectively, Livore *et al.* 2013) and other biota in the food-web during 2003–2010 (drought) and 2010–2013 (post-drought) for Murray Estuary, North Lagoon and South Lagoon (Giatas and Ye 2016). This figure does not represent distributions of fishes, it represents estimated importance of species in the food-web, relative to others. Refer to models CMLE, CMLN, CMLS, CMHE, CMHN and CMHS in Giatas and Ye (2016) for more information. Biotic groupings are (4) *Ficopomatus enigmaticus*, (5) zooplankton, (6) benthic invertebrates e.g. amphipods, polychaetes, insect larvae, shrimp, small crabs, bivalves and gastropods, (7) *Paragrapsus gaimardii*, (8) Australian smelt, (9) sandy sprat, (10) river garfish, (11) bony herring, (12) smallmouthed hardyhead, (13) gobies, (14) greenback flounder, (15) congolli, 16) common carp, (17) Australian herring, (18) flathead gudgeon, (19) yelloweye mullet, (20) black bream, (21) Australian salmon, (22) mulloway, 23) herbivorous waterbirds, (24) shorebirds, (25) piscivorous birds and (26) long-nosed fur seal. Large-bodied fishes with red numbering were collected in low abundance by seine nets and should be viewed with caution.

3 FLOW MANAGEMENT IMPLICATIONS FOR FISHES

River flow is vital for fish populations in the CLLMM region. Most importantly, freshwater inflow influences: (1) water levels, and subsequently habitat availability and salinity, in the Lower Lakes; (2) the establishment of a salinity regime; (3) connectivity between and within freshwater, estuarine and marine environments; and (4) estuarine productivity. Key implications for flow management in relation to population health of fishes in the CLLMM are provided below:

- Water levels in the Lower Lakes strongly influence obligate habitats of threatened small-bodied fish species, which require water levels that maintain lake-fringing and off-channel wetland habitats, and optimise aquatic plant cover and water quality, particularly salinity.
- The abundance of some fishes in the CLLMM, including commercially important estuarine and freshwater species, may be largely influenced by processes initiated outside of the site. Consideration of the spatial dynamics of life-history process will be important for the management of these species in the CLLMM. For example, maintenance of a flow regime in the River Murray that supports the spawning, recruitment and dispersal of golden perch at scales relevant to the life-history of this species.
- Salinity is the key driver influencing the spatio-temporal distribution and critical life-history processes of fishes in the Murray Estuary and Coorong lagoons. Freshwater inflow to maintain a salinity gradient from freshwater to hypermarine is essential to maintain a diverse fish community in this region.
- River inflows into the Lower lakes, Murray Estuary and Coorong lagoons enhances food-web function and resilience, by increasing zooplankton abundance, in turn benefiting zooplanktivorous fishes (e.g. Yarra pygmy perch, smallmouthed hardyhead) and higher order predators.
- Recruitment of large-bodied, marine estuarine opportunist fishes (e.g. mulloway) may be enhanced by higher freshwater inflows, due to increased abundance of small crustaceans and small-bodied fishes (e.g. sandy sprat), as well as the increased area of protected juvenile habitat, facilitating establishment of strong year classes.
- A freshwater plume to provide riverine signatures in the marine environment is necessary to stimulate upstream (return) migrations of anadromous, catadromous and marine estuarine opportunist species.

- Hydrological and physical connectivity between the Lower Lakes, Murray Estuary and Coorong lagoons is critical to allow the obligate downstream and upstream migrations of diadromous species. The provision of connectivity is also important following high flow events to allow the return movements of freshwater species.
- During drought and low flows in the River Murray, the allocation of low-volumes of freshwater to provide inflows through the barrages and fishways meets the critical ecological functions of: (1) maintaining brackish salinities in the Murray Estuary that support estuarine, marine estuarine opportunist and diadromous species; and (2) maintaining connectivity between freshwater, estuarine and marine environments to facilitate obligate migrations of diadromous species.
- Estuarine fish assemblages are dynamic in space and time, hence environmental water allocation and flow management for estuarine fish outcomes need to consider antecedent flow and population/assemblage structure.

4 FUTURE RESEARCH

Understanding the effect of flow on fish population dynamics and important life-history processes is essential for flow management to benefit fishes. Recent research has improved understanding of the impacts of reduced flows on fish assemblages and the life-history of several estuarine, diadromous and freshwater species. The opportunity now exists to consolidate this recently acquired knowledge to address a number of specific knowledge gaps relating to fish–flow relationships and population ecology in the CLLMM region.

For the Lower Lakes, key knowledge gaps include: (1) golden perch population dynamics and the mechanisms underlying recruitment (e.g. the significance of local reproduction as compared to immigration from the River Murray); (2) the impacts of water quality, habitat and connectivity between Lake Albert and Lake Alexandrina on fish populations in Lake Albert; (3) determining the influence of water level fluctuations on threatened fish habitats at a local scale (e.g. aquatic plant structure, food availability, salinity, dissolved oxygen in the channels of Hindmarsh Island) and the corresponding changes to recruitment; (4) understanding the relationships between River Murray flow, water levels and productivity of alien fishes and, in turn, how these potentially influence their interactions with native fish populations in the Lower Lakes; and (5) determination of the trophic pathway supporting the productivity of key species in the Lower Lakes and how their populations are influenced by inflows; e.g. a large-bodied native fish in the Lower Lakes (e.g. golden perch) and a small-bodied native fish in lake-fringing habitats (e.g. Murray hardyhead).

For the Murray Estuary and Coorong lagoons, key knowledge gaps include: (1) relationships between flow and spawning and recruitment of several estuarine, marine estuarine opportunist and anadromous species; (2) the influence of processes occurring beyond the Coorong on the broad-scale population dynamics and habitat requirements of periodic strategist species (e.g. black bream and mulloway) and their ability to establish episodic strong year classes; (4) population models that incorporate flow-biota relationships and fisheries impacts to test hypotheses in relation to management actions; and (5) ongoing collection of baseline data for spatio-temporal variability in estuarine fish assemblages based on probability of occurrence, diversity and abundance (see Sheaves *et al.* 2012).

In particular, extension of the existing time series of fish assemblage monitoring would enable continued assessment of trajectories in assemblage structure during post-drought recovery, providing insights on ecological patterns. Long-term, time-series data are especially valuable for understanding large-bodied, long-lived species. For example, some species, depending on recruitment strategy and age of maturity, may have considerable (e.g. 6+ years for mulloway) lag between favourable environmental conditions for spawning/recruitment and the establishment of a strong year class that persists in the reproductive population. Knowledge of ecological patterns and trajectories may provide insight into underlying ecological processes shaping these patterns and aid the development of hypotheses for future research to determine mechanisms.

The influence of freshwater inflows on estuarine productivity and trophic dynamics requires further investigation. For fish, this includes better understanding of the effects of freshwater inflows on: (1) lower trophic order (e.g. microbiota) responses to flow in freshwater and estuarine ecosystems and subsequent effects on fishes; (2) diets of fish in their early life stages and subsequent recruitment; and (3) interactions of fishes and their predators (e.g. piscivorous birds).

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APPENDICES

APPENDIX A – SOURCES OF DATA AND KNOWLEDGE FOR THE CLLMM MONITORING SYNTHESIS .

Table A-1. Sources of data, and other information, and associated research and monitoring projects that have been used in this synthesis report (this list is not intended to be exhaustive).

Project / Data Source	Data period	Temporal/spatial resolution	Indicators	References
Lower Lakes				
Large-bodied fishes (Fishery data)	1984/85–2013/14	Daily Lake Alexandrina, Lake Albert	Temporal/spatial trends in abundance and assemblage structures for large-bodied fishes Size/age structures for priority species	Ferguson *et al.* 2013; Ferguson and Ye 2016
Small-bodied fish monitoring, including threatened species	2003–2008	Spring and autumn trips Multiple sites in Lake Alexandrina and Lake Albert	Temporal/spatial trends in abundance and assemblage structures for small-bodied fishes including Murray hardyhead (*Craterocephalus fluviatilis*) Yarra pygmy perch (*Nannoperca obscura*) Southern pygmy perch (*Nannoperca australis*)	Higham *et al.* 2005; Bice and Ye 2006; Bice and Ye 2007; Bice *et al.* 2008
Small-bodied fish assemblage monitoring, including threatened species (TLM)	2008/09–2015/16	Spring and autumn trips Multiple sites in Lake Alexandrina and Lake Albert	Temporal/spatial trends in abundance and assemblage structures for small-bodied fishes including Murray hardyhead (*Craterocephalus fluviatilis*) Yarra pygmy perch (*Nannoperca obscura*) Southern pygmy perch (*Nannoperca australis*)	Wedderburn and Hillyard 2010; Wedderburn *et al.* 2012; Ellis *et al.* 2013; Wedderburn *et al.* 2013; Wedderburn 2014; Wedderburn and Barnes 2014; Wedderburn *et al.* 2014a; Wedderburn and Barnes 2016
Critical Fish Habitat Project: Threatened species monitoring	2008–2014	Spring and autumn trips Multiple sites in Lake Alexandrina and Lake Albert	Murray hardyhead (*Craterocephalus fluviatilis*) Yarra pygmy perch (*Nannoperca obscura*) Southern pygmy perch (*Nannoperca australis*) Southern purple-spotted gudgeon (*Mogurnda adspersa*)	Bice *et al.* 2012; Bice *et al.* 2013; Bice *et al.* 2014
Fish monitoring – Goolwa Channel water Level Management Plan	2009–2011	Spring and autumn trips Goolwa Channel and adjacent sites	Temporal/spatial variation in fish assemblages, recruitment patterns and fish condition of key species	Bice and Zampatti 2011a, b
Diet of fish species in the Lower Lakes	2009 and 2011 1984 1981		Redfin perch (*Perca fluviatilis*) and golden perch (*Macquaria ambigua*) Bony herring (*Nematalosa erebi*) Common carp (*Cyprinus carpio*)	Wedderburn *et al.* 2014b Atkins 1984 Hall 1981

Project / Data Source	Data period	Temporal/spatial resolution	Indicators	References
Murray Estuary and Coorong lagoons				
Coorong fish Intervention Monitoring	2010/11–2014/15	November, December, February, March Multiple sites in the Murray Estuary and Coorong lagoons	Temporal/spatial trends in abundance and assemblage structures for large and small-bodied fishes. Size and age structures for priority fish species	Ye *et al.* 2011b; Ye *et al.* 2012b; Livore *et al.* 2013; Ye *et al.* 2015a
Fish movement and recruitment (TLM)	2006/07–date except 2012/13	Murray Estuary	Temporal/spatial patterns of abundance and recruitment of diadromous fish, and fish assemblage variation	Bice *et al.* 2007; Zampatti *et al.* 2010; Zampatti *et al.* 2011a; Zampatti *et al.* 2011b; Zampatti *et al.* 2012; Bice and Zampatti 2014; Bice and Zampatti 2015
Large-bodied fishes (Fishery data)	1984/85–2013/14 2008/09–2014/15	Daily Fishery reporting blocks (10-15 km)	Temporal/spatial trends in abundance and assemblage structures for large-bodied fishes Size/age structures for priority species	Ferguson and Ye 2016
Coorong fish condition monitoring (TLM)	2008/09–2013/14	Four sampling sites in the Murray Estuary and Coorong lagoons	Temporal/spatial trends in abundance, distribution, size/age compositions and recruitment for three priority species: smallmouthed hardyhead, greenback flounder, and black bream	Ye *et al.* 2011a; Ye *et al.* 2011c; Ye *et al.* 2012a; Ye *et al.* 2013a; Ye *et al.* 2015b
CLLAMMecology	2006–2008		FRDC project on flow related fish and fishereies ecology	Noell *et al.* 2009; Ye *et al.* 2013b
Trophic relationships study	2003–2013	2003–2010 and 2010–2013/ Murray Estuary, North Lagoon and South Lagoon	Temporal changes in food-web structure (conceptual modelling). Comparison of low flow (2003–2010) and high flow (2010–2013) periods. Literature review of all previous fish diet and trophic studies within the Murray Estuary and Coorong lagoons	Giatas and Ye 2016
Trophic subsidy study	2014/15	Three sampling events/ Six sampling sites in the Murray Estuary	Spatio-temporal variability in phytoplankton and zooplankton community structure and abundance. Abundance of sandy sprat (*Hyperlophus vittatus*). Stable isotope and gut-content analysis of sandy sprat.	Bice *et al.* 2016
Diet of fish species in the Murray Estuary and Coorong lagoons	1983/84, 2005, 2007 and 2013/14 2007 and 2013/14 2013/14 2005, 2007 and 2012 2007 and 2009/2010		Mulloway (*Argyrosomus japonicus*) Congolli (*Pseudaphritis urvillii*) Australian salmon (*Arripis truttaceus* and *A. trutta*) Yelloweye mullet (*Aldrichetta forsteri*) Greenback flounder (*Rhombosolea tapirina*)	Hall 1986; Geddes and Francis 2008; Deegan *et al.* 2010; Giatas and Ye 2015 Deegan *et al.* 2010; Johnson 2014; Giatas and Ye 2015 Giatas and Ye 2015 Geddes and Francis 2008; Deegan *et al.* 2010; Giatas 2012 Deegan *et al.* 2010; Earl 2014

Project / Data Source	Data period	Temporal/spatial resolution	Indicators	References
Diet of fish species in the Murray Estuary and Coorong lagoons (continued from previous page)	2013/14 and 2014/15		Sandy sprat (*Hyperlophus vittatus*)	Bice *et al.* 2016
	1968–1970 and 2007		Black bream (*Acanthopagrus butcheri*)	Weng 1970; Deegan *et al.* 2010
	2005, 2007, 2010 and 2013/14		Smallmouthed hardyhead (*Atherinosoma microstoma*)	Geddes and Francis 2008; Deegan *et al.* 2010
	2005, 2010 and 2013/14		Tamar River goby (*Afurcagobius tamarensis*)	Geddes and Francis 2008
Life-histories of large-bodied species in the Murray Estuary and Coorong lagoons	1984–2008		Mulloway (*Argyrosomus japonicus*)	Barnes 2015; Ferguson 2010; Ferguson and Ward 2011; Ferguson *et al.* 2008; Ferguson *et al.* 2014
	1984–2012		Greenback flounder (*Rhombosolea tapirina*)	Earl 2014; Earl *et al.* 2014 SARDI, Unpublished data
	1984–2008		Black bream (*Aldrichetta butcheri*) Large-bodied fishes	Ferguson *et al.* 2013

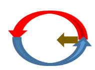
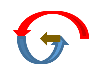
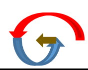
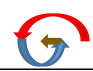
APPENDIX B – LEVEL-OF-EFFECTS TABLES FOR FISH POPULATION INDICATORS

Simple level of effects indicators for fish populations during drought (2003/04–2009/10) and post-drought (2010/11–2014/15) in Lake Alexandrina and Lake Albert and in the Murray Estuary and Coorong lagoons are shown in Tables B-1 and B-2 respectively. These indicators were derived from additional data analysis for projects requested by the Department of Environment, Water and Natural Resources (DEWNR), in particular the following projects:

- small-bodied fish monitoring, including threatened species in the Lower Lakes (e.g. Bice *et al.* 2012; Wedderburn *et al.* 2014a);
- investigating the influences of drought and high freshwater flows on the large-bodied fish assemblage in the Lower Lakes using fisheries data (Ferguson and Ye 2016);
- fish intervention monitoring – assemblage response to flow in the Murray Estuary and Coorong lagoons (e.g. Ye *et al.* 2015a);
- fish movement and recruitment in the Murray Estuary and Coorong lagoons – focusing on diadromous species (e.g. Bice and Zampatti 2015);
- large-bodied fish assemblage in the Murray Estuary and Coorong lagoons – fisheries data (e.g. Ye *et al.* 2015b); and
- conceptual food-web models for the Murray Estuary and Coorong lagoons – focusing on fishes (Giatas and Ye 2016).

In addition to these tables, supplementary unpublished analysis supporting these tables has been provided to DEWNR.

Table B-1. Level-of-effects table for fish indicators during drought (2003/04–2009/10) and post-drought (2010/11–2014/15), relative to Lake Alexandrina and Lake Albert.

Indicators	**Lake Alexandrina**		**Lake Albert**	
Flow period	Drought 03/04–09/10	Post-drought 10/11–14/15	Drought 03/04–09/10	Post-drought 10/11–14/15
Species richness:				
- large-bodied (LB)	⬇	≈	≈	≈
- small-bodied (SB)	≈	↑	↓	↑
Diversity:				
- large-bodied	≈	↑	↕	↕
- small-bodied	≈	↓	↕	⬆
Assemblage structure:				
- large-bodied				
- small-bodied				
Abundance:				
Freshwater native (LB)	⬇	↑	↕	↕
Freshwater native (SB)	↑	↓	↑	⬇
Catadromous	⬇	↑	≈	⬆
Freshwater threatened	⬇	⬇	⬇	⬇
Estuarine	↑	↓	↑	↓
Freshwater exotic (LB)	⬆	⬇	↕	↕
Freshwater exotic (SB)	↑	↓	≈	↓

Key to level-of-effects

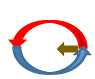
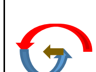
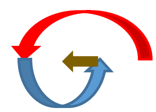
Major decrease	⬇	Major increase	⬆
Minor decrease	↓	Minor increase	↑
Little or no change	≈	Variable – no obvious trend	↕
Trajectory for assemblage structure returned to pre-drought structure		Trajectory for assemblage structure approached but did not return to pre-drought structure	

Table B-2. Level-of-effects table for fish indicators of drought (2003/04–2009/10) and post-drought (2010/11–2014/15) conditions in the Murray Estuary and Coorong lagoons. Refer to the key to level of effect in Table B-1.

Indicators	**Murray Estuary and Coorong lagoons**	
Flow period	Drought 2003/04–2009/10	Post-drought 2010/11–2014/15
Species richness:		
- large-bodied	≈	≈
- small-bodied	≈	↑
Diversity:		
- large-bodied	↓	≈
- small-bodied	≈	↑
Assemblage structure:		
Abundance:		
Freshwater native	↓	↑
Catadromous	↓	↑
Estuarine resident	↓	↑
Marine estuarine opportunist	↓	↑
Freshwater exotic	↓	↑
Marine/estuarine	↓	↑
Trophic structure: food-web complexity	↓	↑