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Influences of drought and high flow on the large-bodied fish assemblage in the Lower Lakes

G.J. Ferguson and Q.Ye

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March 2016

Report to the Department of Environment, Water and Natural Resources

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This project is part of the Coorong, Lower Lakes and Murray Mouth (CLLMM) Recovery Project, which is a key component of South Australia's $610 million Murray Futures program, funded by the Australian Government. The South Australian Government also provided funding support to the Murray Futures program through the Water for the Future initiative. Additional resources and in-kind support were provided for this study by the South Australian Research and Development Institute (Aquatic Sciences, SARDI). In particular, SARDI provided fisheries statistics and library services. Commercial and recreational fishers provided access to samples from catches. Thanks to Dr Paul McEvoy and Adam Watt (Department of Environment, Water and Natural Resources, DEWNR) for providing project management and support. SARDI staff David Short and David Fleer provided field support and Jason Earl contributed age/size data of golden perch. Hydrological information was provided by Jim Foreman (Murray–Darling Basin Authority). Helpful comments on the manuscript were provided by Dr Paul McEvoy (DEWNR) and Chris Bice (SARDI) who reviewed the report.

EXECUTIVE SUMMARY

This study aimed to improve understanding of spatial and temporal variability in the large-bodied fish assemblage in the Lower Lakes of the River Murray in response to restoration of flow and water levels following a period of drought. Firstly, species richness and diversity indices were estimated from commercial fishery data from the Lakes and Coorong Fishery (LCF) from 1984-85 to 2013-14. Secondly, in order to investigate impacts of the Millennium Drought (2000-01 to 2010-11), the assemblage structures of the catches (i.e. relative contribution by species in fishery catches) were compared between lakes Alexandrina and Albert and among four periods: pre- (1998-99 to 2001-02); early- (2002-03 to 2005-06); late- (2006-07 to 2009-10); and post-drought (2010-11 to 2013-14).

Species richness (number of species per year) in the Lower Lakes declined from 1984-85 to 2013-14, largely as a result of species lost from Lake Alexandrina, whilst species richness in Lake Albert was comparatively low in all years. From 2006-07 to 2013-14, catches from lakes Alexandrina and Albert comprised four species: the large-bodied native species; bony herring (*Nematalosa erebi*), and golden perch (*Macquaria ambigua ambigua*); and the introduced species, common carp (*Cyprinus carpio*), and redfin perch (*Perca fluviatilis*).

Temporal variability in assemblage structures differed between lakes Alexandrina and Albert. In Lake Alexandrina, similarity in assemblage structures between pre- (1998-99 to 2001-02) and post-drought (2010-11 to 2013-14) periods suggested that recovery may have occurred in response to high discharge following the end of the drought. However, there was no evidence for such recovery in Lake Albert given variability in assemblage structures among years and differences between pre- and post-drought. In all years, assemblage structures from Lake Alexandrina were dominated by common carp and bony herring although the relative abundance of each species differed among years. During early- (2002-03 to 2005-06) and late- (2006-07 to 2010-11) drought, assemblage structures were characterised by higher contributions from common carp and lower contributions from bony herring. Conversely, during pre- and post-drought, there were higher contributions from bony herring and lower contributions from common carp.

Age structures from fishery-independent sampling of golden perch indicated that recruitment of this species to the population in Lake Alexandrina had occurred since 2010-11. Samples from the

LCF also indicated the presence of older individuals in age structures in 2011-12 compared to the recent drought period, suggesting likely migration of these older age classes into Lake Alexandrina from the River Murray. Importantly, the presence of 3 and 4 year old fish in age structures from 2015-16 indicated that recruitment of younger fish had also occurred in Lake Alexandrina although the relative contributions from local spawning and immigration from the River Murray could not be determined.

1 INTRODUCTION

1.1 Background

The River Murray has been extensively regulated to provide water for consumptive use, primarily irrigated agriculture, with average annual flow at the Murray Mouth now reduced by up to 61% due to diversions for human use (CSIRO, 2008). Furthermore, the River Murray now ceases to flow through the mouth 40% of the time, compared to 1% under natural conditions (CSIRO, 2008). Similarly, water resource development has nearly doubled the average period between the occurrence of flood events that are required to flush the Murray Mouth and help sustain the lake and estuarine ecosystems (CSIRO, 2008).

The recent Millennium Drought (from 2000 to 2010) was the most severe hydrological drought since records started in the late 19th century (Leblanc *et al.*, 2012; Van Dijk *et al.*, 2013). During the drought, the ecological condition of the Lower Lakes, Murray estuary and Coorong lagoons was severely affected by declining water quality (Brookes *et al.*, 2009; Kingsford *et al.*, 2011). From 2006 to early 2010, little flow reached the lower River Murray and water levels in the Lower Lakes receded below sea level for the first time in the 90 year historical record (Mosley *et al.*, 2012), with subsequent impacts including dessication and loss of vegetated habitats, seawater intrusion, lack of flushing, evapoconcentration and increased resuspension (Mosley *et al.*, 2012). In April 2009, the volumes of lakes Alexandrina and Albert were reduced by 64% and 73%, respectively, whilst salinity in both lakes was elevated (Mosley *et al.*, 2012).

Drought conditions ended abruptly in 2010-11, when the region came under the influence of a strong La Niña event that produced the highest recorded mean annual rainfall on record for the Murray–Darling Basin (Leblanc *et al.*, 2012). Water levels and salinity in Lake Alexandrina quickly recovered to pre-drought values.

The Coorong, Lower Lakes and Murray Mouth (CLLMM) program is one of the State Priority Projects established under the Water Management Partnership Agreement through the Council of Australian Governments (COAG). The CLLMM program focuses on managing environmental values of the system consistent with the Long-Term Plan developed by the South Australian Government (DEH, 2010). In addition, the CLLMM program is intended to support international obligations under the Ramsar Convention, and to address risks to threatened and endangered listed species under the *Environment Protection and Biodiversity Conservation Act 1999*.

This study is a component of a broader project titled “Fish monitoring in the Coorong, Lower Lakes and Murray Mouth (CLLMM) region for 2013-14 and 2014-15”. This project also has linkages to another project “Fish monitoring synthesis for the Coorong, Lower Lakes and Murray Mouth” (Ye *et al.* 2016), which provides a complementary analysis of temporal and spatial variability in the species assemblage from fishery catches in the Murray estuary and north and south Coorong Lagoons.

The overall aim of this project was to improve understanding of changes in the large-bodied fish assemblage in the Lower Lakes, after the Millennium Drought (2000–2010), following the environmental changes associated with high flows and restoration of the water levels in lakes Alexandrina and Albert. Specifically, the objectives of this study were to:

- investigate if changes have occurred in assemblage structure of large-bodied fishes post-2010 in the Lower Lakes, based on data from the LCF;
- determine if species diversity has changed post-2010 in the Lower Lakes; and
- to determine the age structure and recruitment of golden perch (*Macquaria ambigua ambigua*) which is a key species.

To achieve these objectives, changes in temporal and spatial patterns in assemblage structures of fishery catch species from the Lower Lakes were analysed. The data set spanned 16 years from 1998-99 to 2013-14 which included the Millennium Drought and pre- and post-drought periods. Demographic information from the commercial fishery, and fishery-independent research sampling were used to further investigate recruitment of golden perch.

2 METHODS

2.1 Study Area

Lakes Alexandrina and Albert which occur at the terminus of the River Murray system are large and very shallow (Figure 2-1). Lake Alexandrina (650.2 km^2), the larger and deeper of the two lakes, has a maximum depth of approximately 4.1 m and a mean depth of 2.9 m at full capacity; Lake Albert (171.5 km^2) is much shallower with a maximum depth of approximately 2.3 m and a mean depth of 1.4 m at full capacity (Mosley *et al.*, 2012). The Lower Lakes are freshwater, eutrophic, and highly turbid (Geddes, 1984; Fluin *et al.*, 2007). Inflows primarily enter the Lower Lakes as surface flow from the River Murray on the north-eastern side and from the Eastern Mount Lofty Ranges via tributaries (including the Finniss, Bremer and Angas rivers, and Currency Creek), groundwater discharge, local run-off, and rainfall on the lake's surface. Lake Albert is a terminal lake and experiences no flow-through from the River Murray (Mosley *et al.*, 2012).

With sufficient flows, water is discharged from Lake Alexandrina through a series of tidal barrages, into the coastal lagoons of the Coorong, out the Murray Mouth and into the Southern Ocean. The barrages, constructed in 1939-40, separate Lake Alexandrina from the Murray estuary, Coorong lagoons and adjacent Southern Ocean, precluding saltwater penetration into the Lake, although less permanent sand bag and wooden barrages were constructed as early as 1914 (Fluin *et al.*, 2007). The 1939-40 barrages' design typically maintains the Lower Lakes at near full capacity at a water level of approximately +0.75 m AHD (Australian Height Datum) (Mosley *et al.*, 2012) and have resulted in a 6% increase in the average areal extent of the Lower Lakes despite the reduced inflows from water development (CSIRO, 2008). Prior to construction of the barrages, Lake Alexandrina was estuarine, although paleolimnological evidence suggests that freshwater dominated because river flows restricted the tidal ingress close to the River Murray Mouth (Fluin *et al.*, 2007).

Beyond the barrages, the Murray estuary (from Goolwa to Mark Point; Figure 2-1), and the North and South lagoons of the Coorong are separated from the Southern Ocean by the dune system of the Younghusband Peninsula (Brookes *et al.*, 2015). The North Lagoon (80 km^2) is historically estuarine and connected to the Southern Ocean by the Murray Mouth. The South Lagoon (80 km^2) is typically hyper-marine (Geddes and Butler, 1984). Although the barrages truncate the estuary, numerous fishways have been constructed to facilitate fish passage between the Coorong and lower River Murray (e.g. Zampatti *et al.*, 2010; Bice and Zampatti, 2015).

2.2 Available information

2.2.1 Environmental

In this report “inflow” refers to freshwater entering Lake Alexandrina from the River Murray then flowing into the Murray estuary through the barrage system. Total flows into the Lower Lakes were simulated using the regression based MSM-BIGMOD (Murray–Darling Basin Authority), a hydrologic model for the Murray–Darling Basin (Fernando *et al.*, 2007) which used modelled inflows into Lake Alexandrina and measured lake level to infer these flows. BIGMOD is a calibrated, validated flow routing model for the main stem of the River Murray which includes irrigation, urban, and drainage diversions; gains and losses from precipitation and evaporation; tributary inflows; and storage by weirs, reservoirs and wetlands. Mean monthly freshwater flows were aggregated into financial years because the highest monthly flows occur during late spring (August–November) and summer (December–February). Data are presented in financial years throughout this report. The unit of freshwater flow is gigalitres per year ($GL.y^{-1}$).

Estimates of mean annual water level (relative to Australian Height Datum (AHD)) were derived from data recorded daily on 12 fixed water monitoring stations located throughout the Lower Lakes (Department of Environment, Water and Natural Resources, DEWNR; Murray-Darling Basin Authority, MDBA). The level of zero m AHD corresponds to the mean sea level in 1967.

2.2.2 Fishery catch composition

The Lower Lakes, Coorong and adjacent ocean beaches support a multi-species, multi-gear fishery; the Lakes and Coorong Fishery (LCF). Since 1984, fishers have been required to submit daily catch and effort data to the South Australian Research and Development Institute (SARDI) on a monthly basis. Daily fishery catch and location (Lake Alexandrina, Lake Albert) data were available from 1984-85 to 2013-14. Fishery data were aggregated into financial years as done for environmental data.

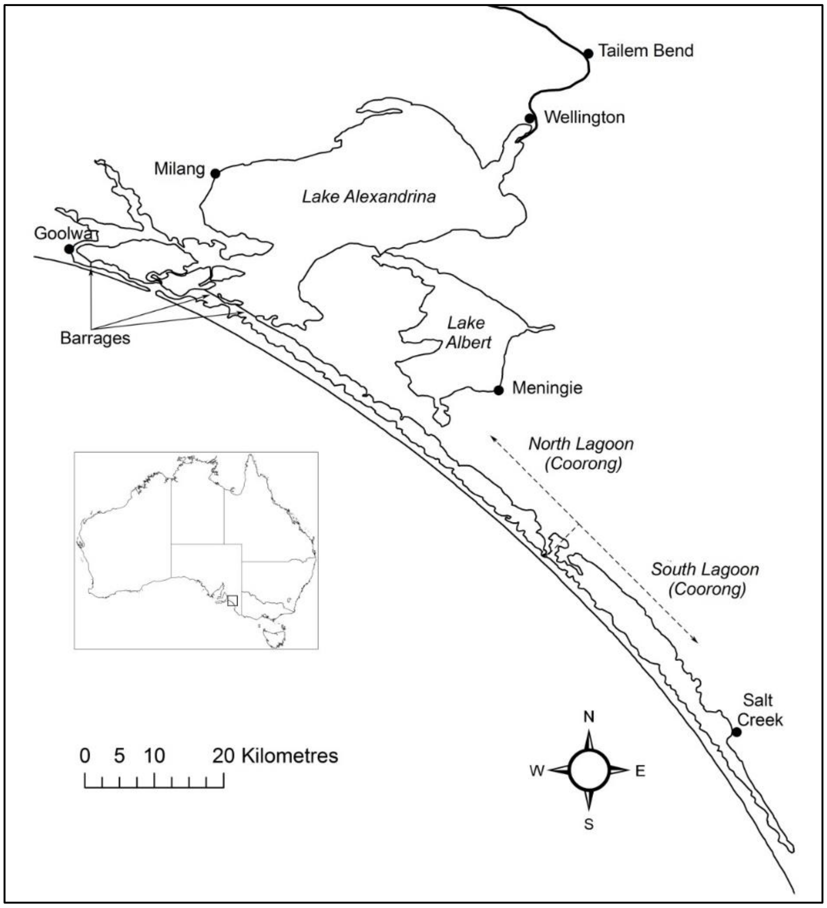

Figure 2-1. Map of lower River Murray system showing the freshwater Lower Lakes comprising lakes Alexandrina and Albert. Also shown are the barrages separating the Lower Lakes from the Coorong Lagoons. Inset is map of Australia showing location of the Coorong and Lower Lakes.

2.3 Analyses

2.3.1 Temporal trends in species richness and diversity

To determine if the species richness and diversity of fishes in the Lower Lakes system had changed over time, indices of richness and diversity were estimated from annual catch data, (1984-85 to 2013-14), at two scales: (i) for the entire Lower Lakes, (including lakes Alexandrina and Albert); and (ii) separately for each of Lake Alexandrina and Lake Albert.

Hill's suite of numbers provide appropriate estimates of species richness and diversity for investigating variations in assemblage structure from fishery catches (Rice, 2000). Species richness (S, Hill's H_0), and two univariate measures of diversity, Hill's H_1 and H_2 (Hill, 1973), were estimated for the entire Lower Lakes region, and separately for Lake Alexandrina and Lake Albert.

Hill's H_1, the exponential of the Shannon function (exp H′) is most sensitive to changes in rare species and Hill's H_2, the reciprocal of Simpson's index (1/D), is most sensitive to changes in abundant species (Krebs, 1989).

2.3.2 Multivariate analysis of assemblage structure (fishery catch composition)

In order to investigate differences among large-bodied fish assemblages before, during and after the Millennium Drought (2000–2010), catch species compositions were compared between lakes Alexandrina and Albert and among four, 4-year periods that included: pre-drought, 1998-99 to 2001-02; early-drought, 2002-03 to 2005-06 which included an experimental flow in January 2005; late-drought, 2006-07 to 2009-10; and post-drought, 2010-11 to 2013-14.

Canonical Analysis of Principal Coordinates (CAP) was used to ordinate the axes (Anderson and Willis, 2003) and compare assemblage structures. Permutational multivariate analysis of variance (PERMANOVA) (Anderson *et al.*, 2005) was used to determine differences in species composition between spatial areas and among time periods. Abundance data were fourth root transformed with all analyses performed on Bray-Curtis similarity matrices. The dependent variables were abundance of catch species with lakes (i.e. Alexandrina, Albert) as a factor and 4-year period nested within lakes. For all CAP and PERMANOVA tests, 4,999 unrestricted random permutations of the transformed data were used (Anderson, 2001). For pairwise comparisons (6 pairs), permutation used in PERMANOVA provides an exact *P* which is robust to type 1 error i.e. there is a 1 in 20 chance of type I error (Anderson, 2001). SIMPER analysis was used to identify species that contributed the most to between group differences. For the CAP analysis, the leave-one-out procedure provided an estimation of the allocation success of catch species structures to the 4-year periods (Anderson and Willis, 2003).

2.3.3 Demographic information for golden perch

Samples of golden perch were sub-sampled from commercial catches (large mesh net, >110 mm stretched mesh) at the point of landing in 2006-07, 2011-12, 2014-15 and 2015-16 to allow analysis of size and age (Table 2-1). Supplementary samples were collected by fishery-independent (research) fishing from October 2006 to January 2007 and on the 10th and 19th of September 2015 using multi-panel gill nets (40, 50, 70, 113, and 153 mm stretched mesh, respectively) which were set overnight in the area between Clayton and Point Sturt with most nets located in and adjacent to the Finniss River. An electrofishing boat was also used to sample golden perch in this area (10th September 2015), using a 5 kW Smith Root Model GPP 5.0 electrofishing unit.

Table 2-1. Location and size of samples of golden perch from commercial and research sampling used in age/size distributions.

Sample	Location	Year	Ages (no.)	Sizes (no.)
Commercial	Clayton to Milang	2007	97	308
Commercial	Clayton to Milang	2011	236	245
Commercial	Clayton to Milang	2014	49	78
Commercial	Clayton to Milang	2015	75	97
Research	Clayton to Point Sturt	2007	37	39
Research	Clayton to Point Sturt	2015	36	36

For each fish, the total length (TL) was measured to the nearest mm and sagittae removed via a cut through the ventral, ex-occipital region of the skull. Sagittae were cleaned, dried and stored in labelled plastic bags. Sagittae from golden perch were embedded in fibreglass resin, and a section cut with a diamond blade mounted on a Gemmasta 6" (150 mm) bench top saw. Each 500 μm thick section was cut so as to incorporate the otolith centre and then mounted on a glass microscope slide using Cyano-Acrylate glue. The mounts were examined using a Leica MZ-16 dissecting microscope with incidental light, and the ages of the fish were determined from counts of opaque zones. Annual periodicity of bands in otoliths has been validated for golden perch in the lower River Murray with the annulus completed in October (Anderson *et al.*, 1992; Stuart, 2006; Zampatti and Leigh, 2013b).

3 RESULTS

3.1 Environmental information

Mean annual freshwater flows into Lake Alexandrina for four periods relating to the Millennium Drought: pre- (1998-99 to 2001-05); early- (2002-05 to 2005-06); late- (2006-07 to 2009-10); and post-drought, (2010-11 to 2013-14) are shown in Figure 3-1. Over this period, annual flows ranged from years with no flow (2002-03 and 2007-08 to 2009-10) to a peak of 12.8 x 10^3 GL in 2010-11. For sequential aggregates of four years, mean flows were 2.5 x 10^3 (±SE 0.98) GL during the pre-drought period, 0.4 x 10^3 (±0.25) GL during the early-drought, <0.1 x 10^3 GL during the late-drought and 7.2 x 10^3 (±2.3) GL during the post-drought period.

Mean annual water levels in Lake Alexandrina remained between normal operating levels from 2001-02 to 2006-07 (0.5–1.0 m AHD) then declined steeply afterwards. From 2007-08 to 2009-10, water levels remained below sea level and were <-0.5 m AHD in 2008-09 and 2009-10. Water levels were >0.5 m AHD from 2010-11 to 2013-14.

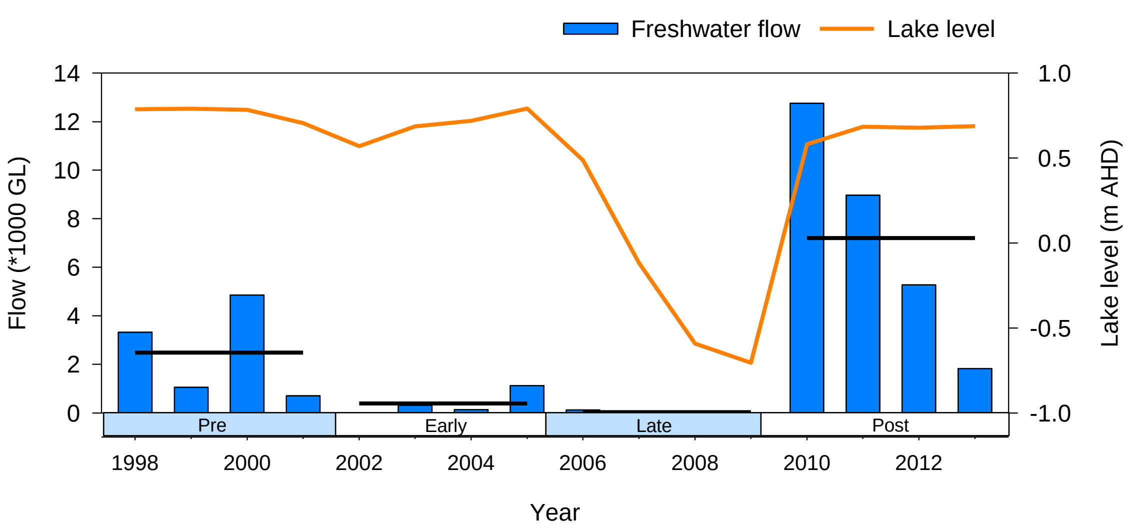

Figure 3-1. Mean annual freshwater flows across the barrages for four, 4-year periods relative to the Millennium Drought: pre- (1998-99 to 2001-02); early- (2002-03 to 2005-06); late- (2006-07 to 2009-10); and post-drought, (2010-11 to 2013-14). Horizontal black lines show average flow for each 4-year period. Orange line shows water level in Lake Alexandrina.

3.2 Species richness and diversity

Within the context of the species mentioned in this section, the reader should note that the native species silver perch (*Bidyanus bidyanus*), and freshwater catfish (*Tandanus tandanus*) were protected by legislation and not available for harvest from 1997-98, and Murray cod (*Maccullochella peelii*), was similarly protected from 2008-09 and subsequently not reported in catch records.

In the Lower Lakes, species richness (Hills H_0) declined consistently from 1984-85 to 1997-98 from 9–5 species (Figure 3-2). During the study period from 1998-99 to 2013-14, species richness was further reduced compared to historical levels and ranged from 4–5 species. Species richness remained stable at four species from 2006-07 to 2013-14. The diversity index Hill's H_1, declined from 1984 to a historically low value in 1989 then increased to a peak in 1994. From 1994-95 to 2000-01, Hill's H_1 remained stable at a historically high level then declined to 2003. Hill's H_1 generally increased from 2002-03 to 20010-11 and the highest historical value occurred in 2011-12. The temporal trend for Hill's H_2 was similar to that of Hills' H_1.

The trend of declining species richness in the Lower Lakes primarily reflects changes within Lake Alexandrina. Species richness (Hill's H_0) for Lake Alexandrina varied from 8–10 species in the mid 1980's and declined consistently to 4–6 species after 1998 (Figure 3-2; Table 3-1). From 2006-07, species richness remained at four species. Notably, a spike in species richness occurred in 2005-06. As for species richness, the trend in species diversity (Hills H_1 and H_2) in the Lower Lakes generally reflected variations experienced in Lake Alexandrina. Species richness in Lake Albert was lower than in Lake Alexandrina and ranged from 4–6 species from 1984-85 to 2004-05, and from then did not exceed four species per year. Species diversity (Hill's H_1, H_2) in Lake Albert was highly variable among years, with the range of variability increasing over time (Figure 3-2).

During 1998-99 to 2013-14, Murray cod were reported in four years (2000-01, 2002-03, 2004-05, 2005-06) from Lake Alexandrina and in one year (2003-04) from Lake Albert, prior to their protection in 2008-09 (Table 3-2). In this period, congolli (*Pseudaphritis urvillii*), was reported in one year from each of Lake Alexandrina (2005-06) and Lake Albert (1998-99). Golden perch, bony herring, common carp and redfin perch (*Perca fluviatilis*), were reported in all years, from both lakes, throughout this period.

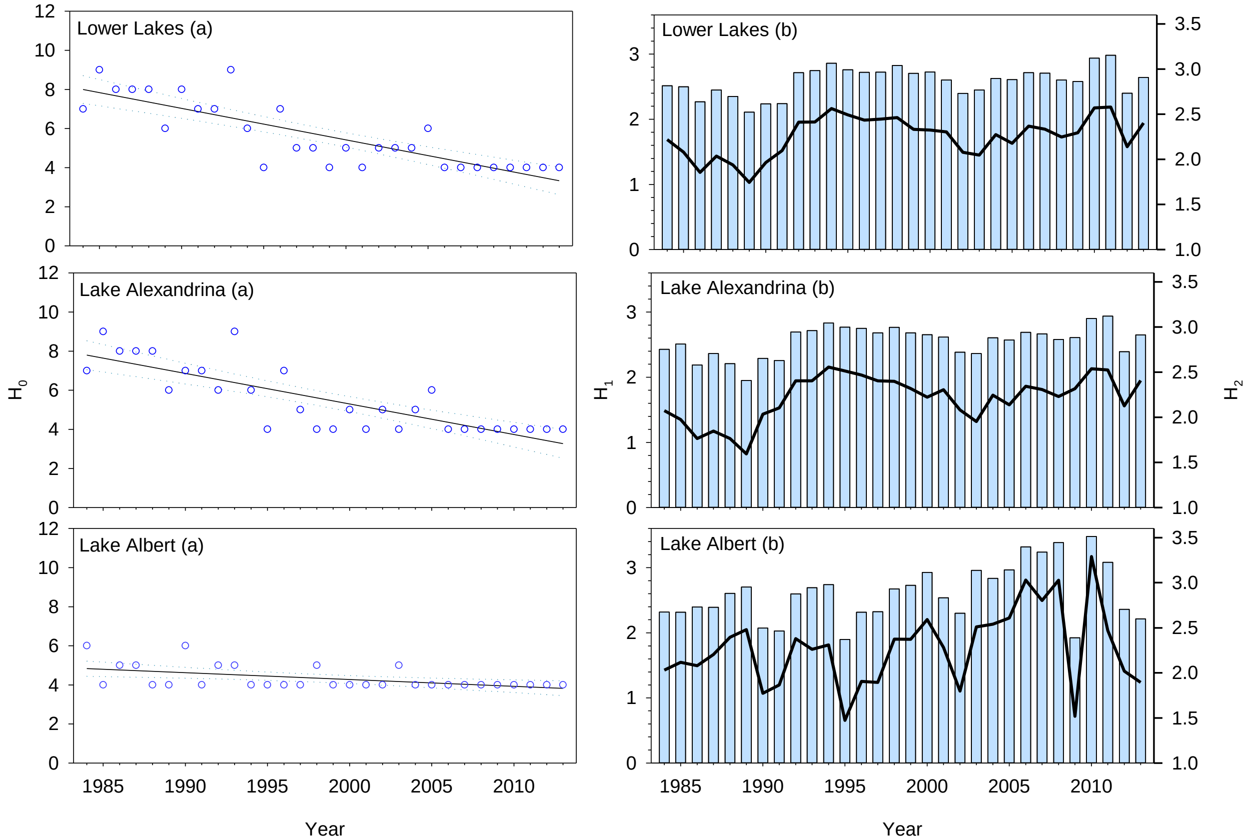

Figure 3-2. Diversity of catch species (Hill's Nos.) from 1984-85 to 2013-14 for catches from the Lower Lakes: (a) Hill's H_0, species richness (no. species present) and (b) Hill's H_1 (bars) which is sensitive to changes in rare species, and Hill's H_2 (line) which is sensitive to changes in more abundant species. Panels on left hand side (a), show linear regression of species richness with time (solid line) and 95% confidence intervals (dotted line). Note that data are reported in financial years; 1985 represents 1985-86.

Table 3-1. Regression statistics for annual estimates of species richness (Hill's H_0) from 1984-85 to 2013-14 in the Lower Lakes. *Slope ≠ 0, t-test.

Habitat	r^2	Slope (±se)	$F_{1,28}$	*P*
Lower Lakes	0.69	-4.28 (0.54)*	61.93	<0.05
Lake Alexandrina	0.66	-4.21 (0.57)*	53.57	<0.05
Lake Albert	0.25	-7.31 (2.37)*	9.52	<0.05

Table 3-2. Time-series of presence/absence of species in commercial fishery catches from 1984-85 to 2013-14. Grey denotes years in which species were protected by legislation.

		1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
Lower Lakes																															
Bony herring	*Nematalosa erebi*	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Brown trout	*Salmo trutta*		×	×	×	×		×	×	×	×			×																	
Golden perch	*Macquaria ambigua ambigua*	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Congolli	*Pseudaphritis urvillii*							×								×							×								
Common carp	*Cyprinus carpio*	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Freshwater catfish	*Tandanus tandanus*	×	×	×	×	×	×	×	×	×	×	×		×																	
Murray cod	*Maccullochella peelii*	×	×	×	×	×	×				×	×			×			×		×	×	×	×								
Rainbow trout	*Oncorhynchus mykiss*		×					×			×			×																	
Redfin perch	*Perca fluviatilis*	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Silver perch	*Bidyanus bidyanus*	×	×	×	×	×			×	×	×																				
Lake Alexandrina																															
Bony herring	*Nematalosa erebi*	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Brown trout	*Salmo trutta*		×	×	×	×		×	×	×	×			×																	
Golden perch	*Macquaria ambigua ambigua*	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Congolli	*Pseudaphritis urvillii*							×															×								
Common carp	*Cyprinus carpio*	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Freshwater catfish	*Tandanus tandanus*	×	×	×	×	×	×	×	×	×	×	×		×																	
Murray cod	*Maccullochella peelii*	×	×	×	×	×	×				×	×			×			×		×		×	×								
Rainbow trout	*Oncorhynchus mykiss*		×								×			×																	
Redfin perch	*Perca fluviatilis*	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Silver perch	*Bidyanus bidyanus*	×	×	×	×	×			×		×																				
Lake Albert																															
Bony herring	*Nematalosa erebi*	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Brown trout	*Salmo trutta*							×																							
Golden perch	*Macquaria ambigua ambigua*	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Congolli	*Pseudaphritis urvillii*															×															
Common carp	*Cyprinus carpio*	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Murray cod	*Maccullochella peelii*	×		×	×						×										×										
Rainbow trout	*Oncorhynchus mykiss*							×																							
Redfin perch	*Perca fluviatilis*	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Silver perch	*Bidyanus bidyanus*	×								×																					

3.3 Assemblage structure

For combined data from freshwater habitats between 1998-99 and 2013-14, large-bodied fish assemblages differed between lakes Alexandrina and Albert and also among the four, 4-year periods (Table 3-3) that included the Millennium Drought: pre-, (1998-99 to 2000-01); early-, (2002-03 to 2005-06); late-, (2006-07 to 2009-10); and post-drought, (2010-11 to 2013-14). Unconstrained CAP showed clear separation of assemblage structures between Lakes Alexandrina and Albert, before, during and after the Millennium Drought (Figure 3-3).

For Lake Alexandrina, pairwise comparison (PERMANOVA) indicated that assemblage composition differed between pre- and early-drought, and also early- and mid-drought periods but was similar between late- and post-drought (Table 3-4). Similarity between pre- and post-drought periods was further demonstrated by the trajectory of annual assemblage structures (CAP; Figure 3-4A). Overall, allocation success for species composition to pre-, early-, late- and post-drought periods was 62.5% (CAP).

For Lake Albert, assemblage structures differed between pre- and early-drought periods but were similar thereafter (Table 3-4). The assemblage structure in the post-drought period in Lake Albert, differed to that during pre-drought, in contrast to the pattern in Lake Alexandrina. Additionally, the trajectory of annual assemblage structures did not indicate similarity between pre- and post-drought periods (CAP; Figure 3-4B). Catch species compositions were allocated to the four, 4-year time periods with 50.0% success (CAP).

Table 3-3. Comparison (PERMANOVA) of catch species between lakes Alexandrina and Albert among four consecutive, 4-year time periods from 1998-99 to 2013-14. *significant difference, α=0.05.

Abundance	df	MS	Pseudo-*F*	$P_{(Perm)}$
Lake	1	7139.10	152.57	<0.001*
Time Period (Lake)	6	142.12	3.04	0.014*
Residual	24	46.79		

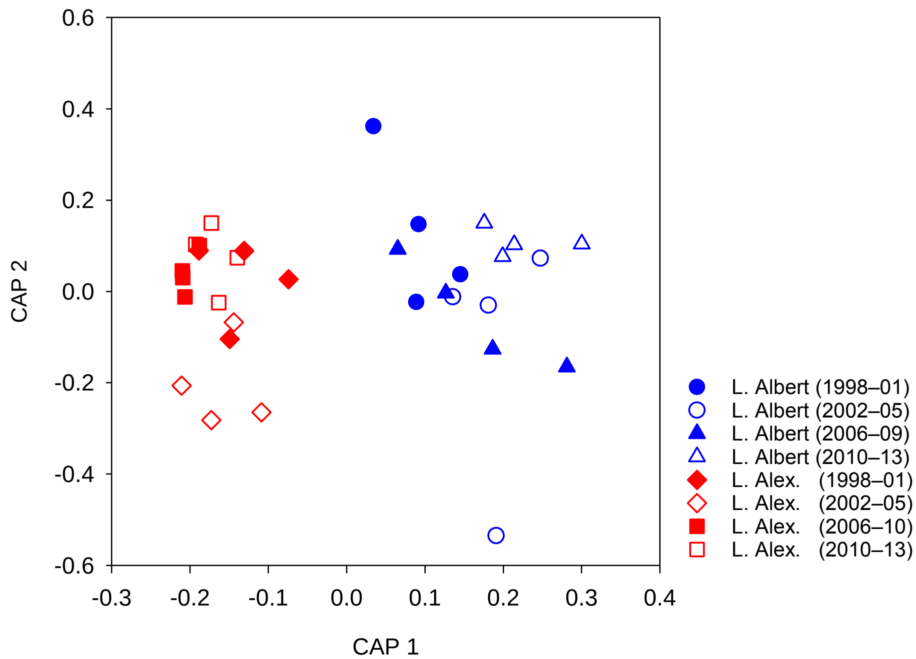

Figure 3-3. Unconstrained canonical analysis of principal coordinates of assemblage structures from lakes Alexandrina (L. Alex) and Albert (L. Albert) during time periods relative to the Millennium Drought: pre- (1998-99 to 2001-02); early- (2002-03 to 2005-06); late- (2006-07 to 2009-10); and post-drought, (2010-11 to 2013-14).

Table 3-4. Pairwise comparison (PERMANOVA) of assemblage structures from lakes Alexandrina and Albert among four consecutive, 4-year time-periods relative to the Millennium Drought: pre- (1998-99 to 2001-02); early- (2002-03 to 2005-06); late- (2006-07 to 2009-10); and post-drought, (2010-11 to 2013-14). *significant difference, α=0.05.

Lake	Time period	t	$P_{(Perm)}$
Lake Alexandrina	Pre ~ Early	2.107	0.029*
Lake Alexandrina	Early ~ Late	2.121	0.030*
Lake Alexandrina	Late ~ Post	2.085	0.060
Lake Alexandrina	Pre ~ Post	1.250	0.244
Lake Albert	Pre ~ Early	2.319	0.027*
Lake Albert	Early ~ Late	0.498	0.884
Lake Albert	Late ~ Post	0.997	0.469
Lake Albert	Pre ~ Post	2.554	0.034*

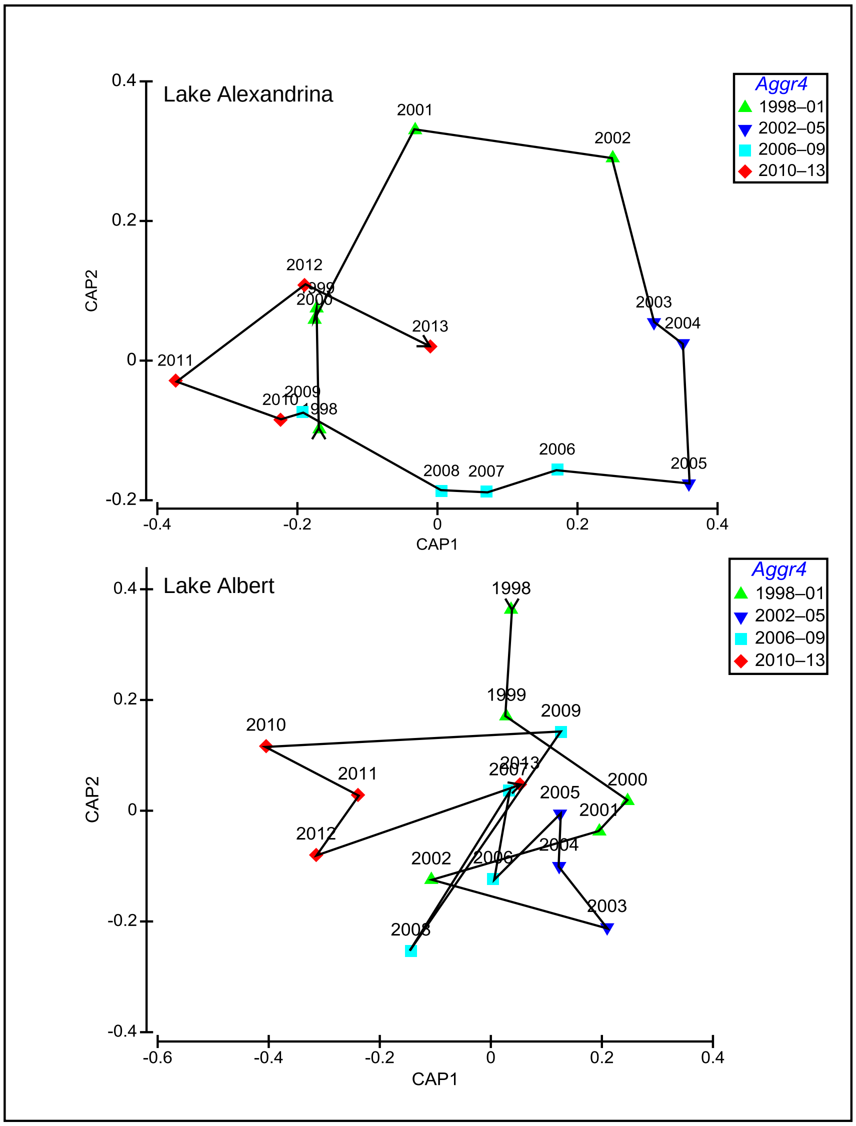

Figure 3-4. Canonical analysis of principal coordinates showing annual trajectories of assemblage structures from 1998-99 to 2013-14 in lakes Alexandrina and Albert. Legend shows four consecutive, 4 year periods relative to the Millennium Drought: pre- (1998-99 to 2001-02); early- (2002-03 to 2005-06); late- (2006-07 to 2009-10) and post-drought (2010-11 to 2013-14).

The main contributions to dissimilarities between lakes Alexandrina and Albert were from bony herring (SIMPER 34%) and common carp (*Cyprinus carpio*) (32%). For the comparison of pre- and post- drought periods in Lake Alexandrina, common carp contributed 26% to between group dissimilarity compared to 33% contributed by bony herring (Table 3-5). For all other comparisons, the contribution to between group dissimilarity by bony herring was similar (early ~ late) to that of common carp or less than that of common carp (pre ~ early; late ~ post).

Table 3-5. Results of SIMPER analysis showing percentage contribution to between group dissimilarities by large-bodied species for four consecutive, 4-year time periods: pre- (1998-99 to 2001-02); early- (2002-03 to 2005-06); late- (2006-07 to 2009-10); and post-drought, (2010-11 to 2013-14) in Lake Alexandrina.

Time period	Average dissimilarity	Common carp	Bony herring	Redfin perch	Golden perch	Murray cod
Pre ~ Early	11.4	30.4	26.7	19.1	12.7	8.1
Early ~ Late	9.5	27.6	28.6	19.8	11.7	10.4
Late ~ Post	10.0	36.0	19.6	20.7	23.7	0.0
Pre ~ Post	11.3	25.9	32.9	21.6	16.2	0.0

3.4 Fishery catches

From 1998-89 to 2013-14, the Lower Lakes contributed 80% of total annual catches from the Lakes and Coorong fishery. In the Lower Lakes during this period, introduced species (common carp, redfin perch) and native species (golden perch, bony herring) each contributed about 50% to the total catch. Patterns in species composition in the Lower Lakes reflected those of Lake Alexandrina which contributed 92% (range 82–99%) of the total annual catches Figure 3-5 (Figure 3-5).

In Lake Alexandrina, the largest differences in catch compositions between pre-, post- and within-drought periods (early-, late-drought) resulted from changes in the contributions from common carp and bony herring. During the pre- and post-drought periods, common carp contributed, 33% and 38% respectively to catch compositions which was less than the contribution during the drought (56–64%). Conversely, bony herring contributed 56% and 51% during pre- and post-drought, respectively, which was higher than the contribution during the drought (27–36%). However, for Lake Albert there was no clear pattern in the percentage contribution from each of the large-bodied species between pre-, post- and within-drought periods.

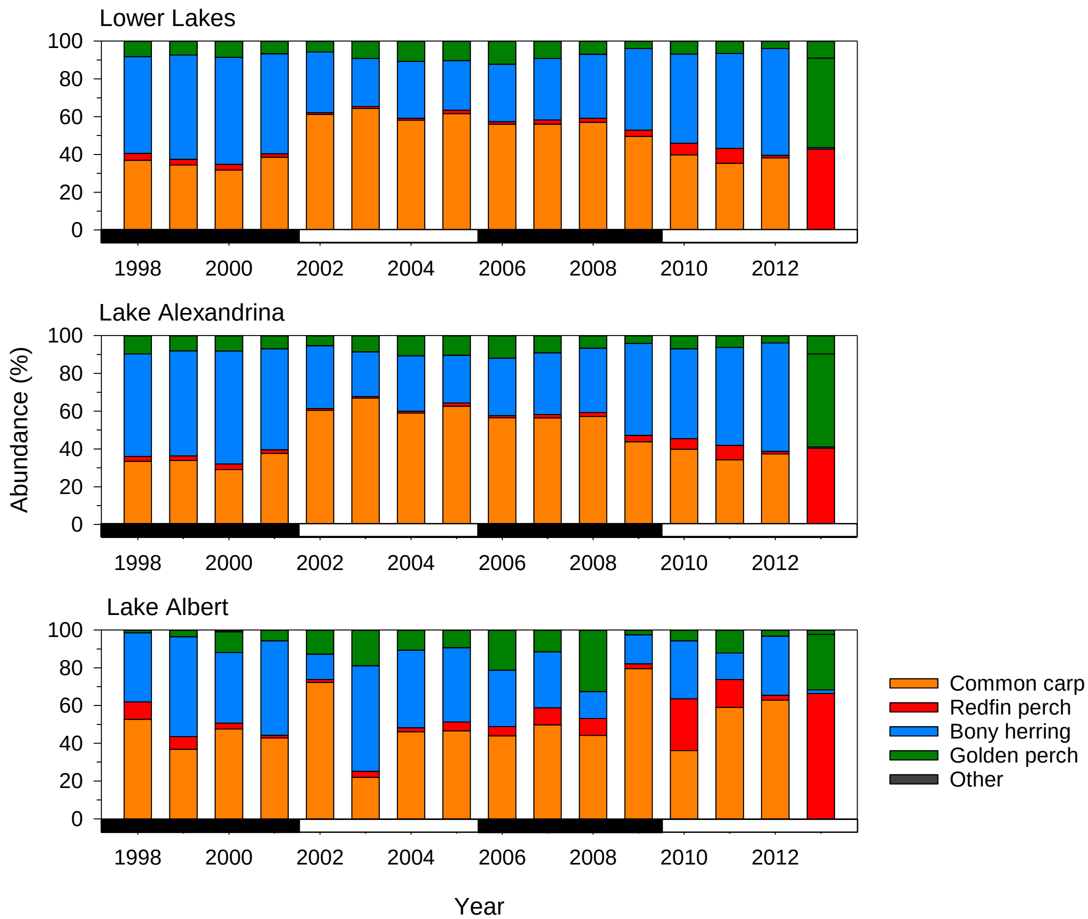

Figure 3-5. Percentage contribution to annual catches by large-bodied fish species in the Lower Lakes, Lake Alexandrina and Lake Albert. (Data presented in financial years, i.e. 1998 refers to 1998-99). Black and white bars on x-axis present pre-, mid-, late- and post-drought periods.

3.5 Demographic information from golden perch

In 2006-07, the ages of golden perch collected from commercial gill nets ranged from 3 to 10 years with a maximum age of 10 years for males and females (Figure 3-6). The age structures were dominated by 6 year olds (50% of samples), originating from spawning in 2000-01 with a secondary mode of 10 year olds (17%) originating from 1996-97.

The range of ages present in commercial nets in 2011-12 was significantly broader than that for 2006-07 with a range of 2–21 years for females and 4–20 years for males (Kolmogorov-Smirnov, K-S: Z=2.546, P=0.001) (Figure 3-6). The dominant mode of 5 year olds comprised 25% of samples with secondary modes at 8 (15%), 11 (6%) and 15 years (5%). Whilst the dominant mode of 6 year olds present in the age structure from 2006-07 was not strongly represented in 2011-12, the secondary mode of 10 year olds persisted as 15 year olds in 2011-12.

For age structures from commercial catches in 2014-15, ages ranged from 3–15 years with a dominant mode of 5 year olds (31%) and a secondary mode of 9 year olds (8%) (Figure 3-6). The age range in 2014-15 had contracted compared to that in 2011-12 (2–21 years). In 2015-16, the age structure had contracted further (4 to 13 years) with a dominant mode of 5 year olds (48%), originating from 2010-11. The dominant modes of 6 year olds in 2006-07 and 5 year olds from 2011-12 were not represented in 2015-16.

The range of ages (1–9 years) present in age structures from multi-panel gill nets from a research program in 2006-07 (Figure 3-7) was slightly broader than that from commercial gill nets (3–10 years) likely due to gear selectivity, with the presence of recent recruits (1–2 year olds) (K-S: Z=1.952, P=0.001). For the age structures from research samples in 2006-07, significant modes occurred at 3 (24%), 4 (22%), and 6 (24%) years, compared to one strong mode (48%) at 6 years in the structure from commercial nets. In 2015-16, the age structure from research nets ranged from 3 to 5 years and was dominated by 3 year olds (53%), with lesser contributions from 4 (28%) and 5 (19%) year olds (Figure 3-7).

Age structures from research and commercial netting also differed (K-S: Z=1.553, P=0.016) in 2015-16. The range of ages from research netting (3–5 years) was smaller than that from commercial nets (4–13 years). Nonetheless, age structures of golden perch from research nets in 2006-07 and 2015-16 were based on smaller sample sizes (n<40) than those from commercial samples.

Overall, size was poorly related to age for golden perch because there was a narrow range of sizes (340–540 mm) present in size distributions from commercial gill nets but ages ranged from 3–22 years. Size distributions from research multi-panel gill nets were broader than those from commercial nets and ranged from 160–460 mm TL in 2006-07 and 180–440 mm TL in 2015-16.

Sex ratios (n_f:n_m) for golden perch in Lake Alexandrina were biased towards females in all years. In 2006-07, the sex ratio from commercial net samples was 2.6:1 (n_f=70; n_m=27), as compared to that of 1.4:1 (n_f=18, n_m=13) from research sampling. In 2011-12, the sex ratio from commercial net samples was 4.8:1 (n_f=176; n_m=37). In 2015-16, the sex ratio from commercial sampling was 3:1 (n_f=21, n_m=7) and from research sampling was 3.7:1 (n_f =11; n_m=3).

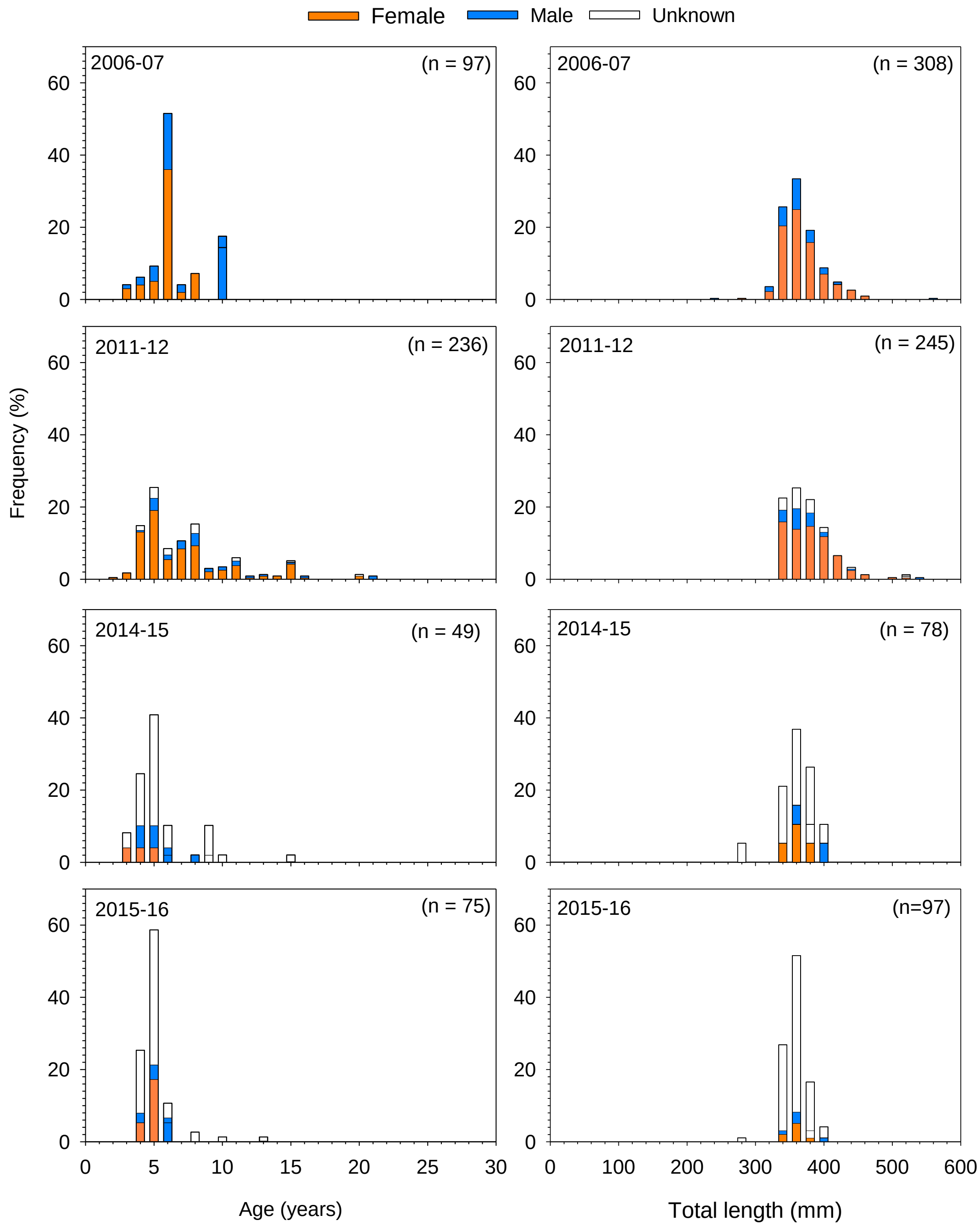

Figure 3-6. Age and size of golden perch from commercial catches in Lake Alexandrina in 2006-07, 2011-12, 2014-15 and 2015-16.

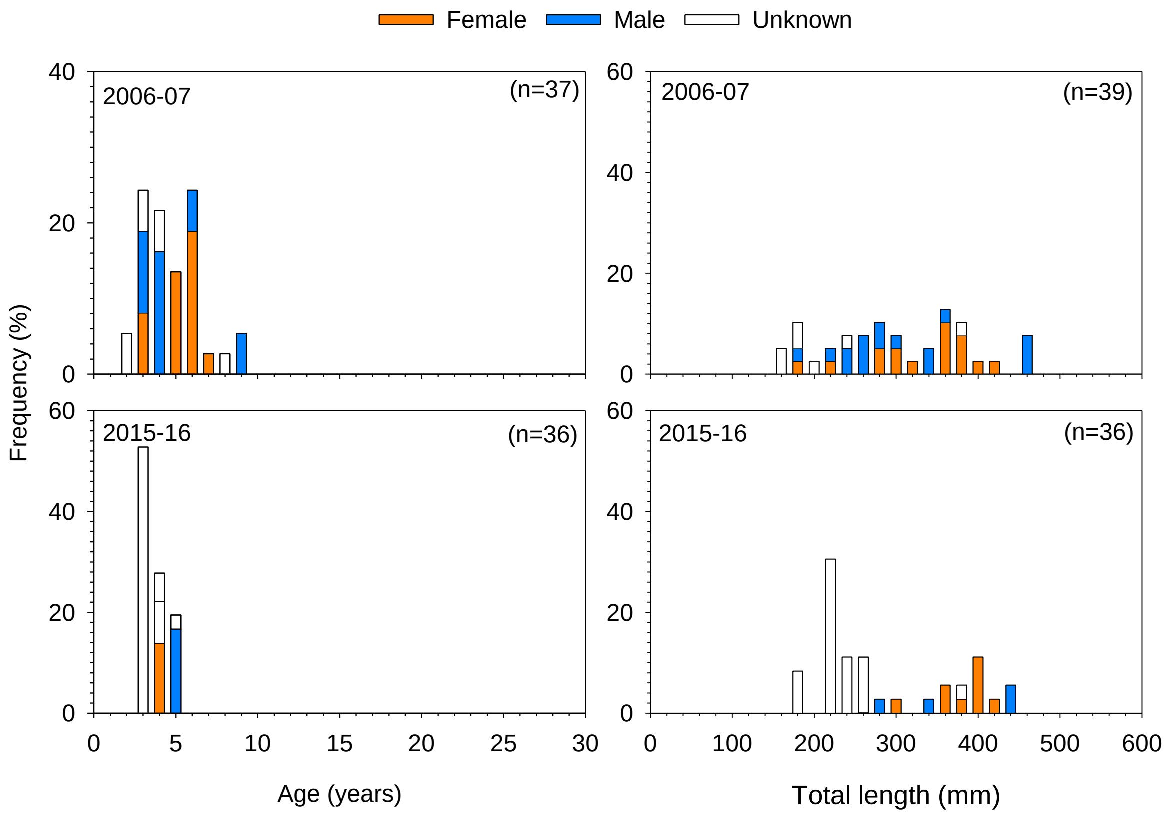

Figure 3-7. Age and size of golden perch from research netting and electrofishing in Lake Alexandrina in 2006-07 and 2015-16.

4 DISCUSSION

Patterns in the relative contributions of large-bodied species in fishery catches indicated that assemblage structures differed temporally and spatially. The use of fishery data in this study assumes that species diversity has not been affected by changes in fishing patterns. Management arrangements and levels of total annual fishing effort in the LCF were consistent among years during this study supporting this assumption (Ferguson *et al.* 2013). In the Lower Lakes, species richness declined from nine species in 1985-86 to five species in 1998-99 and four species after 2006. The long-term, declining trend in species richness in the Lower Lakes mainly reflects the declining trend in Lake Alexandrina. These results are consistent with those of a previous study, using similar methods that compared the species composition of large-bodied fishes from 1984-85 to 2008-09 (Ferguson *et al.*, 2013). Declining species richness in annual catches was partly attributable to the exclusion of the native species silver perch and freshwater catfish as a result of their protection since 1997, although silver perch ceased to be reported in catches in 1993. Similarly, Murray cod have not been reported in catches since 2005 and have been protected since 2008. Declining species richness was also partly attributable to the introduced species brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) which contributed to higher species richness prior to 1996, but have not been reported since.

Large-bodied species present in commercial catches in this study were consistent with those from several fishery-independent research studies (Wedderburn *et al.*, 2003; Bice *et al.*, 2008b, 2010). Congolli, bony herring, and golden perch were reported from research sampling in lakes Alexandrina and Albert *circa* 2003 (Wedderburn *et al.*, 2003) and from multiple sites in Lake Alexandrina in 2007 and 2008 (Bice *et al.*, 2008a). The exotic species, redfin perch, common carp and goldfish, were also reported from research studies in Lake Alexandrina in 2003, 2007 and 2008 (Wedderburn *et al.*, 2003; Bice *et al.*, 2008a). In addition, Bice *et al.* (2010) reported two exotic species that were not recorded in fishery catches in this study; goldfish (*Crassius auratus*) and tench (*Tinca tinca*).

Patterns in the relative contributions of large-bodied fish species to fishery catches provide insight into changes in assemblage structures before, during and after the Millennium Drought. In the Lower Lakes, temporal patterns in assemblage structures from 1998-99 to 2013-14 differed between Lakes Alexandrina and Albert and largely reflect patterns in Lake Alexandrina. In Lake Alexandrina, the post-drought assemblage structure was similar to that during pre-drought which was further illustrated by the trajectory of annual assemblage structures that showed increasing dissimilarity between subsequent years from 1998 to 2005, followed by decreasing dissimilarity each year until 2010. These patterns suggest a degree of recovery of large-bodied species likely associated with increased flow from the River Murray and recovery of water levels and salinity values in Lake Alexandrina after 2010 (Leblanc *et al.*, 2012). For Lake Albert, temporal patterns in assemblage structures were less well defined suggesting that recovery to the pre-drought state may have been comparatively slow. This may be because water quality did not return to pre-drought conditions as quickly as in Lake Alexandrina. Although salinity levels in Lake Albert, declined after the drought they had not returned to pre-drought levels in October 2013 (DEWNR, 2014). Peak salinity levels in Lake Albert during the drought were >2.5 times higher than those in Lake Alexandrina and this terminal lake has no direct connectivity to the sea with all water inflow from Lake Alexandrina via the Narrung Narrows. Consequently, the ability for salt to be naturally exported from the system is limited (DEWNR, 2014).

Lack of difference in assemblage structures between late-drought and subsequent flooding in the Lower Lakes may be partly due to constant high biomass of the opportunistic strategist species, common carp and bony herring that recruit annually, relative to golden perch which do not recruit each year (Puckridge and Walker, 1990; Smith, 2005; Zampatti and Leigh, 2013a). This was supported by the low contribution from golden perch (12–24%) to between-group dissimilarities among 4-year periods during the study period (1998-99 to 2013-14) compared to common carp and bony herring (>60%).

Recruitment of golden perch to the population in Lake Alexandrina since 2010 is suggested by the dominance of 3 (53%), 4 (28%) and 5 (19%) year olds, in age structures from research sampling in 2015-16, representing spawning in 2012-13, 2011-12, and 2010-11, respectively. These results were supported by the dominance of 5 year olds (59%) in age structures from commercial catches in 2015-16. Although unlikely to be fully recruited to commercial nets (i.e. large enough to be vulnerable to the nets), 4 year olds were also present in age structures from commercial catches in 2015-16 (25%) and 2014-15 (25%). In 2006-07, age structures from Lake Alexandrina ranged from 3–10 years suggesting annual recruitment from 1999–2003 with modes at 6 and 10 years suggesting relatively strong recruitment in 1996-97 and 2000-01. For Lake Albert, patterns in age structures from commercial catches in 2009-10 were consistent with those from Lake Alexandrina and ranged from 2–12 years and with multiple age classes suggesting that recruitment occurred annually between 1996-97 and 2006-07 (Bice, 2010).

Because golden perch are known to move large distances, it is not known whether the recruits present in age/size structures in Lake Alexandrina were spawned there or migrated from elsewhere in the River Murray system (O'Connor *et al.*, 2005; Zampatti and Leigh, 2013a; Zampatti *et al.*, 2015). Differences in the range of ages present in age structures from commercial catches in 2006-07 and 2011-12 suggest that migration from the River Murray to Lake Alexandrina may have occurred during or after flooding in 2010-11. In 2006-07, the oldest year class in the age structure comprised 10 year olds but in 2011-12 the age structure was broader and more complex with ages up to 21 years. Additionally, in 2006-07 modes of 6 and 10 year olds present in age structures from Lake Alexandrina were also present in those from the lower River Murray but in 2011-12 age structures between the two locations differed substantially (Zampatti and Leigh, 2013a). It should be noted that whilst age structures of golden perch from Lake Alexandrina differed among years, size structures were similar suggesting that size structures are unlikely to provide a reliable indication of changes in population status with age structures providing the more robust indicator.

Future Research

Further research is required to understand the mechanism underlying recruitment to the golden perch population in the Lower Lakes. Population age structures and abundance of golden perch in the Lower Lakes vary among years due to differences in recruitment, migration, or more likely, a combination of both; consequently, it is important to understand the relative contributions of these processes. The natal origin and movement patterns of golden perch could potentially be investigated using geochemical signatures in otoliths (Elsdon *et al.*, 2008; Zampatti and Leigh, 2013a) in combination with other methods (e.g. acoustic telemetry, external tagging).

Conclusion

Trends in species richness and diversity of large-bodied fish species in fishery catches from the Lower Lakes, particularly from Lake Alexandrina, indicate that species richness of large-bodied fishes has declined over 30 years. In Lake Alexandrina, patterns in the composition of large-bodied fish species in fishery catches suggest that recovery from the drought may have occurred because post-drought (2010-11 to 2013-14) and pre-drought (1998-99 to 2001-02) assemblages were similar and characterised by higher contributions from bony herring relative to years during the drought (2001-02 to 2005-06, 2006-07 to 2009-10).

For golden perch, which is a large-bodied native species with a periodic strategist life-history (Winemiller and Rose, 1992; Winemiller, 2005) and flow-related recruitment (Ferguson *et al.*, 2013; Zampatti and Leigh, 2013a), the presence of 3 and 4 year olds in the age structures in Lake Alexandrina in 2015-16 suggest that recruitment has occurred since post-drought flooding in 2010-11.

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