Fisheries

Stock Assessment of Golden perch (*Macquaria ambigua*)

G.J Ferguson and Q. Ye

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Fishery Stock Assessment Report to PIRSA Fisheries and Aquaculture

Government of South Australia

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Cover photograph courtesy of Jason Higham (DEWNR).

EXECUTIVE SUMMARY

1 This report is the second assessment of the South Australian fishery for golden perch (*Macquaria ambigua*).

2 Golden perch is an important species in the Lakes and Coorong Fishery and in 2010-11 comprised 4% of the total catch and 19% of the total catch value.

3 Peak annual catches occurred in 1994-95 (206.4 t) and 2006-07 (151.9 t). From 2006-07, catches declined steeply to 2010-11 (67.4 t).

4 Most catches of golden perch (long-term average (±SE), 94 ±1.2%) were from Lake Alexandrina with the remainder from Lake Albert.

5 In Lake Alexandrina, annual targeted effort was closely related to targeted catch.

6 CPUE declined from an historic peak of 13.1 kg.fisher day^{-1} in 1993-94 to 4.9 kg.fisher day^{-1} in 1999-00. CPUE then increased to a secondary peak of 12.6 kg.fisher day^{-1} in 2006-07 before declining to 6.5 kg.fisher day^{-1} in 2010-11.

7 Ages of golden perch from Lake Alexandrina in 2006-07 ranged from 3-10 years (n=73) with a dominant mode at 6 years and a secondary mode at 10 years. In 2011-12 ages ranged from 3-22 years (n=195) with a dominant mode at 5 years and a secondary mode at 15 years. A greater number of year classes were represented in 2011-12 compared to 2006-07.

8 The most important knowledge gaps for the fishery for golden perch in Lake Alexandrina are: (i) spatial resolution of catches of golden perch; (ii) levels of discarding of sub-legal sized fish; (iii) an estimate of discard mortality; and (iv) an estimate of recreational catches. Important biological knowledge gaps are: (i) an estimate of size at maturity; (ii) development of a recruitment index; and (iii) an improved understanding of the influence of freshwater inflows on recruitment.

9 All performance indicators are based on fishery catch/effort data and were within the range of reference points prescribed in the Management Plan.

10 Available information suggests that golden perch in Lake Alexandrina are sustainably exploited. CPUE (kg.fisher day^{-1}) declined steeply from 2006-07 to 2010-11 suggesting a decline in relative abundance. However, age classes from 6-9 years were well represented in the age structure from 2011-12. Additionally, the presence of small juveniles (<1 year old) in barrage fish-ways below Lake Alexandrina suggest that recruitment occurred in 2010-11.

11 Age structures should be monitored regularly (i.e. each 5 years) to reduce reliance on CPUE as an indication of population status.

1 GENERAL INTRODUCTION

1.1 Overview

This is the second stock assessment of golden perch (*Macquaria ambigua*) in South Australia and builds on the stock assessment in 2004 (Ye 2005). The aim of the report is to provide a comprehensive synopsis of information available for the Lakes and Coorong Fishery (LCF) for golden perch and to assess the current status of the resource.

The report is divided into five sections. Section one provides the General Introduction which: (i) outlines the aims and structure of the report; (ii) describes the history of the Lakes and Coorong Fishery for golden perch; and (iii) provides a synopsis of biological and ecological knowledge of golden perch.

Section two provides a summary of the fishery statistics for the Lakes and Coorong Fishery for golden perch from 1984-85 to 2010-11. Information presented in this section includes inter-annual patterns in catch, effort and catch-per-unit-effort (CPUE), intra-annual trends in catch and a comparison of effort measures (fisher day, net day) available for the fishery in Lakes Alexandrina and Albert.

Results from recent research on age/size of golden perch in South Australia are shown in Section three.

Section four assesses the performance of the fishery for golden perch against the performance indicators specified in the Lakes and Coorong Fishery Management Plan (Sloan, 2005). Potential additional performance indicators are examined (e.g. otolith based age structures).

Section five is the General Discussion. It synthesises information presented in the previous sections of the report, assesses the status of the fishery and the level of uncertainty in the assessment, and outlines future research needs.

1.2 Description of the fishery

1.2.1 Commercial fishery

The Lakes and Coorong Fishery (LCF) is a multi-species, multi-gear fishery and is located in, and adjacent to, the estuary of the Murray River (Figure 1-1). This comprises the Coorong lagoons, Lower Lakes of the Murray River (Lakes Alexandrina and Albert) and Coorong Coastal Waters (Sloan 2005). Fishers in the LCF primarily use gill nets to target mulloway (*Argyrosomus japonicus*), golden perch (*Macquaria ambigua*), yellow-eye mullet (*Aldrichetta forsteri*), black bream (*Acanthopagrus butcheri*), and greenback flounder (*Rhombosolea tapirina*). Fishers in the LCF also have access to pipi (*Donax deltoides*) on the ocean beach adjacent the Coorong lagoons.

The LCF is the only commercial fishery permitted to take golden perch in South Australia. Golden perch is an important target species in the LCF and in 2010-11 comprised 4% of the total catch (all species) of the LCF and 19% of the total value (all species) (Knight and Tsolos 2012). For catches comprising finfish only, golden perch contributed 5% of the catch and 27% of the value in 2010-11 (Knight and Tsolos 2012).

Figure 1-1. Map of Coorong region showing fishery reporting blocks for golden perch catches from Lakes Alexandrina (4) and Albert (5).

The LCF is governed by the *Fisheries Management Act 2007*, which came into effect in December 2007, the Fisheries Management (Lakes and Coorong Fishery) Regulations 2009 and the Fisheries Management (General) Regulations 2007. Goals for the LCF are consistent with the objectives of the *Fisheries Management Act 2007* and are outlined in the Management Plan for the Lakes and Coorong Fishery (Sloan, 2005).

The fishery is managed as a limited entry fishery. Currently there are 36 licences with non-exclusive access within the Lakes and Coorong system. Fishing effort is limited through gear entitlements. For example each licence is endorsed for the type and number of nets that can be used. Owner-operator provisions also apply so that gear must be set and retrieved by the licence holder, or a nominated skipper (registered master).

Licence amalgamations were permitted under the Scheme of Management introduced in 1984 to promote economic efficiency by allowing fishers to rationalise individual gear entitlements from within the existing pool of licences. In 1990, following an agreement between PIRSA and the commercial industry, a policy directive was introduced to formalise a set of guidelines on licence amalgamations and transfers. A key element of the policy is the limitation placed on the amount of gear that may be endorsed on an individual licence upon licence transfer or amalgamation. Under the policy, a maximum of two agents may undertake fishing activity pursuant to each licence, following the transfer of a licence. Specific arrangements apply to licence transfers between members of a family. All applications for licence transfer or amalgamation must be considered in accordance with the *Fisheries (Scheme of Management - Lakes and Coorong Fishery) Regulations 1991.* This ‗amalgamation scheme' has allowed for limited structural adjustment of the commercial sector by reducing the number of licences and the amount of gear operating in the fishery over time.

The Management Plan for the Lakes and Coorong Fishery identifies four performance indicators (PIs) and their associated reference points (RPs). All PIs were derived from catch and effort data for the historical reference period from 1984-85 to 2001-02 (Sloan 2005). Upper and lower reference points for the catch and CPUE RPs were the estimated highest and lowest values during the reference period. Upper and lower trend (rate-of-change) PIs for catch and CPUE were estimated from the highest and lowest slope of the linear relationships for 4 year periods within the reference period (Sloan 2005).

The LCF is managed in the context of a number of international legal instruments including the Ramsar Convention and the United Nations Convention on the Law of the Sea. In addition, the fishery operates within the boundaries of the Lakes and Coorong National Park, an area recognised primarily for its wetland habitats and importance for a variety of migratory waterbirds.

Catch and effort data for the commercial fishery for golden perch in South Australia have been recorded since 1984 (Knight et al. 2001). Daily catch and effort information is provided on a monthly basis to SARDI Aquatic Sciences, including; catch, effort (days, fisher days, number of nets) and fishing location. Management arrangements for the commercial fishery for golden perch comprise general gear restrictions, spatial and temporal closures and a legal minimum size (LMS) of 330 mm total length (TL).

Table 1-1. Management milestones for the Lakes and Coorong Fishery

Date	Milestone
1906	The South Australian Government introduced a requirement for all commercial fishers to hold a commercial fishing licence.
1971	Introduction of fishing licences for all commercial fishing in South Australia
1972	Licensed commercial fishers required to provide monthly catch data
1982	*South Australian Fisheries Act, 1982*
1984	Scheme of Management (Lakes and Coorong Fishery) Regulations 1984 Scheme of Management (Marine Scalefish Fisheries) Regulations 1984 Scheme of Management (Restricted Marine Scale Fishery) Regulations 1984
1984-85	The LCF was divided in to 16 areas for the purpose of data collection and more detailed fishing location information was collected from operators.
1986	Restrictions on commercial net type, mesh size, net depth and net length. Limit of one registered recreational net per person, with 70 m total length and maximum of 1 m drop.
1990	Guidelines formalised to limit the amount of gear that may be endorsed on an individual licence upon licence transfer or amalgamation.
1991	Fisheries (Scheme of Management—Lakes and Coorong Fishery) Regulations 1991 Fisheries (Scheme of Management—Marine Scalefish Fisheries) Regulations 1991
1997	Review of the recreational fishery
2003	Closure of the river fishery
2004	Amendments to the Scheme of Management to allow an individual to hold more than one licence.
2005	Management Plan for the South Australian Lakes and Coorong Fishery
2006	Fisheries (Scheme of Management – Lakes and Coorong Fishery) Regulations 2006 Fisheries (Scheme of Management – Marine Scalefish Fishery) Regulations 2006
2007	*The Fisheries Management Act 2007* Fishery Management Committees were discontinued from 31 March 2007.
2009	*Fisheries Management (Lakes and Coorong Fishery) Regulations 2009*

1.2.2 Recreational fishery

Recreational fishers harvest golden perch using rod and line. Additionally, recreational fishers are also allowed to fish in Lakes Alexandrina and Albert with registered nets. However, there is little information available on recreational catch and effort targeted at golden perch in South Australia (Jones and Doonan 2005; Jones 2009).

The recreational fishery is open access and managed with general gear restrictions and bag/boat limits (Sloan, 2005). A bag limit of five golden perch per fisher per day, and a boat limit of 15 golden perch, applies to this fishery in addition to a size limit of 330 mm TL. However, bag and boat limits for recreational species are currently being reviewed by PIRSA. Gear is restricted to a total of either two handlines, two rods or one of each and the fisher must be in attendance. In addition to a rod and handline a person can have one of:

- One mesh net (registered) and either one hand net or one shrimp trap;
- One hand net and one shrimp trap; or
- 3 yabbie pots; or
- 3 drop nets; or
- 10 hoop nets; or
- 3 hoop nets and 1 mesh net, and either one hand net or one shrimp trap; or
- 3 hoop nets and one hand net and one shrimp trap.

In 2012, approximately 770 recreational fishers possessed a registered mesh net. Mesh nets must be: 110–150 mm (4 1/4” to 6”) mesh size, less than 75 m long, and the registered net owner must be within 50 m of the net at all times when fishing.

1.2.3 Traditional fishery

The Ngarrindjeri population density is likely to have been the largest of any aboriginal group in Australia with an estimated 3000 people inhabiting the Coorong region in the 1800s, prior to European settlement (Sloan 2005). The Ngarrindjeri people targeted several species including bream and flounder and smoked and dried fish for storage and trading (Jenkin 1979). Species targeted by the Ngarrindjeri people and associated levels of catch and effort are poorly understood.

All of the management measures in place for the recreational sector currently apply to indigenous fishers when undertaking traditional fishing practices.

1.3 Stock assessment

1.3.1 Commercial fishery

Previous information on the resource status of the Lakes and Coorong fishery for golden perch comprises (i) a stock assessment (Ye 2005) and (ii) stock status reports for the Lakes and Coorong Fishery (Pierce and Doonan 1999; Ferguson 2006a; Ferguson 2006b; Ferguson 2008; Ferguson 2010; Ferguson 2011; Ferguson 2012).

In South Australia, catch rates of golden perch have varied greatly among years and catches tend to be highest in summer-autumn (Pierce and Doonan 1999; Ye 2005; Ferguson 2012). Key points from the stock assessment of Ye (2004) were:

- Historically, 56% of commercial catch was from the Murray River with 44% from the Lower Lakes (Lake Alexandrina and Lake Albert);
- Catch rose to a peak in 1994-95, then fell substantially to a low level in 2001-02;
- CPUE rose to a peak in 1992-93 then declined to a low level in 2001-02;
- Trends in catch and CPUE were likely due to several strong year classes related to floods in 1989 and the early 1990‘s;
- Golden perch take 4.6 years to recruit to the LCF in the Lower Lakes;
- Uncertainties exist around (i) reproduction (size at maturity, intra-annual trends in gonad development, recruitment), (ii) migration, and (iii) the role of environmental factors in recruitment and reproduction of golden perch. There were also uncertainties around (i) the level of recreational catches, and (ii) the level of incidental mortality of sub-legal sized golden perch discarded from gill nets;
- The stock was depleted in 2001, despite strong year classes from 1998 and 2000;
- Flow management should provide regular within channel flows or floods because it is likely that year class strength is related to freshwater flows.

1.3.2 Recreational fishery

Estimates of the recreational catch of golden perch in South Australia are available for two years: 2000-01 and 2007-08. In 2000-01, the estimated catch (±95% confidence interval) was 86,732 (±12,086) golden perch which was 91.1 t (Jones and Doonan 2005). The overall release rate was 69% (Jones and Doonan 2005). The highest catches occurred in upper and lower reaches of the Murray River with release rates 58-67% (Jones and Doonan 2005). Most recreational catches were taken by line, although recreational net fishers who have access to golden perch in Lake Alexandrina may have been under-represented (Jones and Doonan 2005).

In 2007-08, 39,861 ±16,027 golden perch were harvested with an overall release rate of 24.3% (Jones 2009). The harvested catch was an estimated 46.5 t which comprised 28.4% of the combined commercial and recreational catch in that year (Jones 2009).

There is currently no estimate of the size composition of golden perch harvested by the recreational fishery in South Australia. Short-term post release mortality of golden perch caught by recreational line fishers from rivers in New South Wales ranged from 0% to 24% in winter and summer, respectively (Hall et al. 2012).

1.4 Fisheries biology

1.4.1 Taxonomy

Golden perch (*Macquaria ambigua*) belongs to the Family Percichthyidae. Seven species and one sub-species in the genera *Macquaria* and *Maccullochella* have been found in south-eastern Australian fresh waters. The accepted common name for *Macquaria ambigua* is golden perch but they are also known as callop (indigenous name), yellowbelly, perch, Murray perch and white perch.

1.4.2 Geographical distribution and habitat

Golden perch occur throughout most of the Murray-Darling system with the exception of higher altitudes as well as in the Lake Eyre and Bulloo internal drainage systems of Queensland, New South Wales and South Australia, and the Dawson-Fitzroy river system in south-eastern Queensland (Lake 1967c; Lake 1971). They are also widespread within the Lower Murray River and Lakes Alexandrina and Albert (Bice 2010b).

The natural distributional range and abundance of golden perch declined following European settlement (Lake 1967c; Cadwallader and Backhouse 1983; Battaglene and Prokop 1987; Cadwallader 1977b). Whilst golden perch no longer occur over large areas of the Murray-Darling tributaries or in the higher reaches of the main channels, the species remains abundant in the lower Murray-Darling rivers (Mallen-Cooper 1993; Pierce 1995; Harris and Rowland 1996). The main cause of this decline has been habitat degradation, especially through the construction of numerous dams and weirs that obstruct migration and alter natural regimes of flow and water temperature (Lake 1971; Reynolds 1976; Cadwallader 1978; Pollard et al. 1980; Brumley 1987; Cadwallader and Lawrence 1990; Koehn and O'Connor 1990; Mallen-Cooper 1993; Walker and Thoms 1993). Dams and weirs also impede movement of golden perch during small river rises (Mallen-Cooper 1994a).

Golden perch mainly occur in warm, turbid, slow-flowing inland rivers and associated floodplain lakes and anabranches (Lake 1971; Merrick and Schmida 1984). They prefer deep pool habitats with woody debris such as dead trees or fallen timber, undercut banks or rocky ledges (Cadwallader 1979; Battaglene and Prokop 1987). Golden perch are well adapted to the naturally dynamic stream flow conditions of the Murray-Darling system (Lake 1967a; Mackay 1973; Harris and Gehrke 1994). They can withstand extremes in water temperature (4-37°C) (Harris and Rowland 1996) and salinity (up to 14,400 ppm) (Jackson and Pierce, unpublished data).

1.4.3 Growth

Golden perch is a long-lived (maximum age 26 years), large-bodied species that commonly reaches 400-500 mm TL but may reach a maximum size of 760 mm TL (6.3 kg) (Mallen-Cooper and Stuart 2003). Ages of golden perch have been estimated from whole otoliths, tagging studies and otolith sections (Jones 1974; Reynolds 1976) (Table 1-2). Anderson et al. (1992) reviewed age and growth of golden perch using samples collected over a 40-year period. Samples were from the lower Murray-Darling Basin including stocked and natural populations from lacustrine and riverine habitats in the Murray River, Murrumbidgee River and their Victorian and Southern NSW tributaries. In this study, ages were determined from thin transverse sections of the sagittae of 889 fish. Bands in the sagittae were formed annually and completed in October for all ages, although this may have varied with latitude. The accuracy of ageing from thin sections was estimated as >95%, with an average percent error of 4%. Validation of ages was done for fish to 8 years old (455-545 mm TL, 1.7-4.0 kg total weight) by analysis of: (i) modal progression in length distributions; (ii) marginal-increment analysis; and (iii) analysis of age estimates of fish from populations with a known stocking history. Consistency in the growth of the otoliths and the appearance of annual marks suggested that estimates were accurate to 16 years (530-600 mm TL) (Anderson et al. 1992b).

Growth has been estimated (von Bertalanffy growth function, VBGF) from historical (1949-1951) and recent (1984-1991) collections of golden perch otoliths (Anderson et al. 1992b). The highest growth rate occurred in the first four years of life then slowed from 6 to 10 years old (Table 1-2) with no difference in growth rate found between males and females. High variability in growth was observed among locations and years. For example, faster-growing 1-year-old fish may be longer and heavier than slow-growing 5-year-olds. The asymptotic maximum length (L_{inf}) of 500 mm TL was consistent among recent and historical otolith collections (Anderson et al. 1992b). High growth rates (K=0.45-0.46) were also consistent among recent and historical collections of otoliths. Similarly high growth rates were also estimated for the population in the Murumbidgee River (Mallen-Cooper and Stuart 2003).

The spatial differences in growth and maximum size observed by Anderson et al. (1992) were also found in the Darling, Murray, and Murrumbidgee rivers, where individuals from productive impoundments grew to a larger size than those from the river systems (Mallen-Cooper and Stuart 2003) (Table 1-3). The variability in the growth rates and maximum size of this species is likely due to climate, habitat and food resources (Battaglene and Prokop 1987).

Although the maximum recorded age is 26 years, maximum ages (<16 years) in age structures are typically lower, which has been attributed to loss of older fish from the sampled populations and truncation of the age distribution (Mallen-Cooper and Stuart 2003). The study of Anderson et al. (1992) found the maximum size for male and female golden perch to be similar. However, other studies found that females grew to a larger size than males in the Murrumbidgee in Lake Keepit, NSW (Battaglene 1991; Mallen-Cooper and Stuart 2003).

Whilst considerable work has been conducted on populations of golden perch from the mid-upper Murray River, growth patterns in the population from Lakes Alexandrina and Albert have not been well described.

Table 1-2. A comparison of the estimates of lengths-at-age and von Bertalanffy growth parameters of different populations of golden perch (*Macquaria ambigua*).

Source	Time	Location	N	Ageing method	Age (years)										Growth parameters		
					1	2	3	4	5	6	7	8	9	10**	L_{inf} (mm)	K	t_o (years)
Jones (1974)	1973-1974	Lower River Murray, SA	130	Whole otoliths	162	281	368	425	463	499	528	562	588	--	--	0.33	--
Reynolds (1976a)	1974-1976	Lower River Murray, SA	37	Tagging	170	300	380	430	470	--	--	--	--	--	--	0.53	--
Anderson *et al*. (1992b)	1949-1991	Murray, Murrumbidgee and their Victorian and Southern NSW tributaries and lakes	874	Otolith sections	200	301	370	420	427	459	500	502	510	508	507	0.45	0.42
	1984-1991	Murray, Murrumbidgee and their Victorian and Southern NSW tributaries and lakes	796	Otolith sections	202	302	369	426	428	497	490	504	--	--	501	0.46	0.44
	1949-1951	Murray and Murrumbidgee	78	Otolith sections	--	333	381	403	427	443	517	470	510	508	589	1.47	-3.71
Mallen-Cooper and Stuart (2003)*	1990-1992	Impoundments	88	Otolith sections	172	279	360	421	468	503	529	549	564	576	611	0.28	-0.18
	1990-1992	Murrumbidgee River	95	Otolith sections	29	200	309	379	424	452	470	482	489	494	502	0.45	0.87
	1990-1992	River Murray	216	Otolith sections	72	222	307	355	383	398	407	412	414	416	418	0.57	0.67
	1990-1992	Darling River	39	Otolith sections	111	215	275	309	328	339	346	349	351	352	354	0.56	0.33

* Note: the mean lengths-at-age in this study are calculated from the von Bertalanffy equations.

** Although the longevity of golden perch is 26 years, length increment mainly occurs during the first 10 years.

Table 1-3. A comparison of the estimates of von Bertalanffy growth parameters for females, males and all fish using historical (1949-1951) and recent (1984-1991) collections of golden perch (*Macquaria ambigua)*.

Group	n	Length (mm)			Age (years)			Growth parrameters		
		Mean	Min.	Max.	Mean	Min.	Max.	L_{inf} (mm)	K	t_o (years)
Females	133	405.6	120	604	4.94	1.39	16.1	544	0.317	-0.111
		± 8.05			*± 0.217*			*± 21.6*	*± 0.044*	*± 0.218*
Males	72	364.5	135	600	4.27	1.39	16.1	527	0.326	0.071
		± 10.4			*± 0.284*			*± 23.1*	*± 0.31*	*± 0.054*
All fish	874	327.0	86	604	3.12	0.90	16.1	507	0.454	0.420
		± 3.06			*± 0.059*			*± 4.61*	*± 0.012*	*± 0.030*
Recent	796	310.0	86	600	2.88	0.90	16.1	501	0.461	0.435
		± 3.0			*± 0.51*			*± 9.71*	*± 0.035*	*± 0.107*
Historical	78	435.7	323	604	5.75	2.08	16.1	589	1.47	-3.71
		± 6.61			*± 0.273*			*± 47.8*	*± 0.052*	*± 1.70*

1.4.4 Size at maturity

Female golden perch in populations in the Murray River usually mature at 4 years and males at 2 years (Mallen-Cooper and Stuart 2003). There is no formal estimate of size at maturity (SAM) available for golden perch in Lake Alexandrina (i.e. based on the size class at which 50/90% of golden perch are mature). Given that growth is highly variable it is likely that SAM is variable also.

1.4.5 Reproduction

Golden perch are known to spawn during spring and summer (Battaglene and Prokop 1987) with extended spawning periods (autumn, winter and spring) also possible (Ebner et al. 2012). A histological study has shown that all eggs are shed in a single spawning (Mackay 1973) although multiple spawning could occur under favourable conditions (Battaglene and Prokop 1987). Fecundity in golden perch is related to fish size and age (Lake 1967b; Rowland et al. 1983; Battaglene and Prokop 1987). For example a 2.3 kg female (about 500 mm TL) may shed up to 500,000 eggs (Lake 1967b).

The main stimulus for spawning is flooding or rise in river level at temperatures ranging from 18-25°C (Battaglene and Prokop 1987; Ebner et al. 2012). This is consistent with experimental results where an increase in temperature to 23 °C was found to induce spawning (Lake 1967d). In the absence of suitable stimuli female golden perch are known to undergo ovarian involution and resorb the eggs (Mackay 1973).

1.4.6 Early life-history

Mature oocytes are spherical, with a diameter of 1.1 mm and are amber in colour (Rowland et al. 1983), non-adhesive and semi-buoyant, requiring a gentle current to keep them suspended in the water column. In floodwaters development is pelagic and hatching takes 24-33 hours at 20-31 °C (Lake 1967a; Rowland et al. 1983). Newly hatched larvae are 3.5-4.0 mm TL, poorly developed with a relatively small yolk sac, semi-buoyant and float upside-down. The yolk is almost fully absorbed and the jaws functional by 96 hours after hatching. The larvae (5.0-5.5 mm TL) are very active, and can swim against a gentle current and start schooling. Five days after hatching (age D6) larvae disperse and commence feeding on zooplankton.

Metamorphosis completes at 15-18 mm TL (age D19-28), 14-23 days after feeding commences. Survival rates of larvae are thought to be influenced by the timing of the spawning event (Mackay 1973; Harris and Gehrke 1994). Floods release accumulated nutrients from the catchment which trigger a succession of plankton blooms, providing food for larvae (Arumugam and Geddes 1987; Geddes and Puckridge 1988; Puckridge and Walker 1990; Rowland 1992).

1.4.7 Recruitment

Golden perch are considered to be flood-pulse specialists (Lake 1967c; Harris and Gehrke 1994). The flood pulse concept assumes that floods enhance recruitment (Harris and Gehrke 1994). This may be through spawning in response to flooding, or increased larval survival from increased larval food availability during flooding, particularly from inundated flood plains (Junk et al. 1989). However, considerable speculation exists around the role of flooding in the spawning and recruitment of golden perch.

The flood recruitment model is consistent with the ―flood-pulse concept" (Junk et al. 1989) which is appropriate for large, low-gradient river systems with productive floodplains such as the Murray River system. However, this model (Harris and Gehrke 1994; Lake 1967d) does not discriminate between the two roles of flooding, either: (i) controlling gonadal maturation and spawning behaviour, as in the adult phase of the flood-recruitment model; or (ii) enhancing survival and growth of cohorts of larvae and juveniles, as in the larval phase of the model, irrespective of the factors which induced spawning. The significance of recruitment during flows confined to channels has been emphasised in more recent studies (Humphries et al. 1999; Mallen-Cooper and Stuart 2003). Within-channel flows may sustain lower levels of recruitment between flood years when larval survival may be much greater (Mallen-Cooper and Stuart 2003). High larval survival also depends upon the presence of high concentrations of appropriate size zooplankton (Arumugam 1986; Rowland 1996a).

A recent study found that spawning and recruitment success of golden perch in river habitats in New South Wales and Victoria increased during a managed flood event in 2005 although the exact cause of the response was unknown (King et al. 2009). This study also suggested a degree of flexibility in spawning requirements and that low levels of spawning activity also occurred during regulated within-channel flows (King et al. 2009). Similarly, in South Australia, golden perch were found to spawn concurrently with the managed flow release (Ye et al. 2008). It is likely that a range of environmental conditions need to occur for successful spawning and recruitment of golden perch to occur: (i) coupling of high flows and elevated temperatures; (ii) a flood/flow pulse that is predictable for the particular river system; (iii) a slow rate of rise and fall in water level; (iv) the flood period endures over several months; and (v) for the Barmah-Millewa region a large proportion of the flood plain is inundated (King et al. 2003).

Spawning and recruitment may also occur during within-channel flows (Mallen-Cooper and Stuart 2003) and periods of no flow (Balcombe et al. 2006). Age-verified year class strength data, collected over three years, indicated that recruitment of golden perch was high in non-flood years and low in flood years supporting a non-flood recruitment model, however, the location of spawning and nursery sites were unknown (Mallen-Cooper and Stuart 2003).

From 2002 to 2009, the Murray River experienced the worst drought in history (CSIRO 2008; MDBC 2008; Lester and Fairweather 2009) (Figure 4-1). Larval surveys conducted between Locks 1 and 6 in the lower Murray River found larvae in 2005, but not 2006, 2007 or 2008 (Cheshire and Ye 2008b; Ye et al. 2008; Bucater et al. 2009; Cheshire 2010). The presence of larvae in 2005 likely resulted from a managed flow event in that year (Ye et al. 2008; King et al. 2009) whilst the absence of larvae in 2006 and 2007 likely indicated lack of spawning success (Cheshire and Ye 2008b; Ye et al. 2008; Bucater et al. 2009; King et al. 2009).

Flooding of the lower Murray River occurred from September 2001 (Figure 4-1). Electro-fishing surveys found 0+ golden perch in the Murray River channel near Katarapko creek in April 2010 and Chowilla in 2010 and 2011 although it is thought that these recruits originated from the Darling River system (Beyer et al. 2011; Leigh and Zampatti 2012).

Little is known of the role of flooding in spawning and recruitment success for the population of golden perch in Lakes Alexandrina and Albert (Bice 2010b). Fish assemblages in and near the Goolwa Channel below Lake Alexandrina were studied using multi-panel gill nets and fyke nets in March-April 2011. Small (<1 year old, 0+) golden perch were present in catches from this study (Bice and Zampatti 2011). Similarly, large numbers of small (<1 year old) golden perch were collected during spring-summer from fish-ways constructed on the barrages below Lake Alexandrina in 2010-11 although only one golden perch was collected in 2009-10 (Zampatti et al. 2011; Zampatti et al. 2012). These results are supported by the trend in gonad condition of golden perch from Lake Alexandrina which suggested that spawning occurs in spring-summer (Mayrhofer 2007).

1.4.8 Diet

Golden perch are opportunistic carnivores. The larvae and small juveniles feed primarily on zooplankton, primarily copepods or cladocerans (Lake 1967c). At first feeding, golden perch larvae prefer slow swimming cladocerans (*Moina spp.* and small *Daphnia spp.*) over faster swimming copepods (*Boeckella spp.*) of a similar size-class (Arumugam 1990), but can also take copepod nauplii and early stage copepodites (Rowland 1996a). From 12-24 mm TL, they can catch and eat a range of zooplankton (*Moina spp., Boeckella spp., Daphnia spp.*) and become generalist zooplanktivores, although feeding is limited by mouth gape. From 25 mm TL, chironomid larvae also become an important component of the diet (Culver and Geddes 1993; Rowland 1996a). From 37 mm TL larger *Daphnia spp.* are consumed (Arumugam and Geddes 1987; Arumugam and Geddes 1992). The rapid shift from gape-limited to size-dependent to large-size prey selectivity is consistent with the optimal foraging theory (Arumugam and Geddes 1992).

Delay in feeding of *M. ambigua* larvae may result in significant mortality. Rowland (1996) indicated that a delay of initial feeding of only two days (to age D8) significantly reduced survival, and a delay of four days (to age D10) could result in complete mortality.

For river populations of golden perch ephemeral floodplain habitat is thought to be the nursery ground for larval and juvenile golden perch (Geddes and Puckridge 1988; Gehrke 1990). Floodplains are rich in nutrients with accumulated organic detritus (Briggs and Maher 1983; Briggs et al. 1985) and hold reserves of resistant stages of microinvertebrates that emerge with flooding (Boulton and Lloyd 1992). In newly inundated floodplains, the crustacean zooplankton undergo successional stages involving *Moina spp.*, *Boeckella spp.*, *Daphnia spp.* and *Bosmina spp.* (Timms 1989) and populations of chironomid larvae also develop rapidly (Maher and Carpenter 1984), which provide food for fish larvae.

Larger fish feed during the day and at night (Merrick and Schmida 1984) mainly on crustaceans, insect larvae, molluscs and fish (Stephenson and Grant 1957; Llewellyn and MacDonald 1980) with goldfish and common carp a major dietary component in some areas (Cadwallader 1979). In Lake Keepit, NSW and in rivers in Queensland the diet may be seasonal with fish such as bony herring, gudgeons, common carp and goldfish comprising the major part of the diet in winter and crustaceans in summer (Merrick 1985; Battaglene and Prokop 1987). When fresh ground is inundated, following flooding, terrestrial and aquatic insects dominate the diet of adult fish.

1.4.9 Stock structure

Recently, significant bio-geographic structure associated with drainage basins has been identified among populations of *M. ambigua* in eastern Australia using mitochondrial DNA methods (Faulks et al. 2010). This is consistent with early work, also based on genetic methods which found at least four population groups: (i) the Murray-Darling basin; (ii) Lake Eyre internal drainage basin; (iii) Bulloo River basin; and (iv) the Fitzroy drainage basin which suggested that these populations have been isolated from each other for considerable, and different lengths of time (McDonald 1978; Musyl and Keenan 1992). The Lake Eyre population appears to be a different stock at the species level from golden perch found in other drainage basins, while the Fitzroy and Murray-Darling populations diverged at the sub-species level (McDonald 1978; Musyl and Keenan 1992).

Another study, based on electrophoresis has shown that relatively isolated stocks with limited-gene flow occur within the Murray-Darling basin (Harris and Rowland 1996). Samples from 26 sites and across seven polymorphic loci identified seven separate stocks of golden perch within the basin (Keenan et al. 1995). Overall, a central Murray River stock overlapped much of the lower and mid-basin waters with six smaller populations (Figure 1-2). The presence of a headwater stock of golden perch is consistent with the higher level of spatial structuring possibly present in the tributary system. Even though golden perch can migrate extensively (Reynolds 1983; Koehn and Nicol 1998), gene flow is clearly not uniform across all geographical areas, which results in genetic differences between some stocks.

The central stock represents the dominant golden perch stock within the Murray-Darling basin. The population abundance of this stock is distinctly flood-linked, with massive upstream migration producing pelagic eggs and larvae, which then reseed lower river reaches. The presence and influence of this genotype reaches down to the lower Murray lakes.

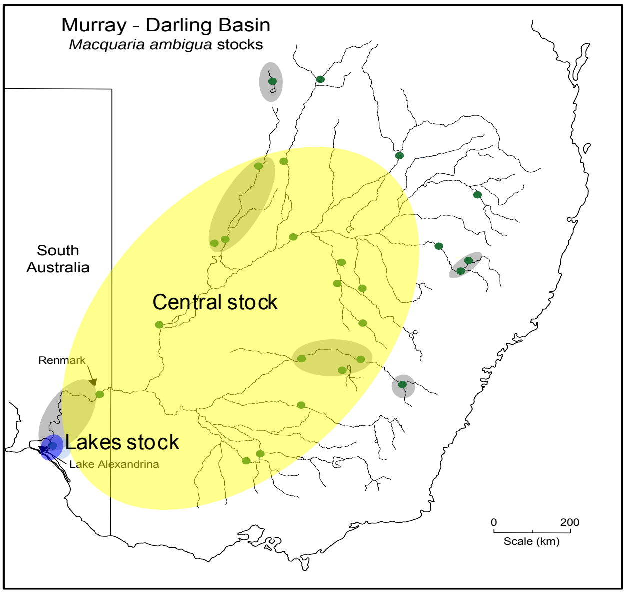

Figure 1-2. The six minor genetic stocks identified within the Murray-Darling drainage basin (Keenan et al. 1995). The Murray River central stock (yellow) occupies and overlaps the lower and central component of the drainage and the Lakes stock (purple) occurs in Lakes Alexandrina and Albert.

In addition to the central stock of golden perch Keenan et al (1995) also identified a genetically distinct stock in Lakes Alexandrina and Albert. Prolonged periods of major drought in the Lower Lakes have resulted in periods of minimal available freshwater habitat consequently the Lakes stock may have become a distinct genotype which has increased in abundance since barrage construction. Such a stock would have undertaken significant local migration into freshwater refugia such as the Finniss River during periods of extreme drought. Alternatively, the lakes stock may have evolved since barrage construction was completed in 1940. It has been demonstrated (Kimura and Weiss 1964; Keenan 1994) that in linear (as opposed to three dimensional) systems, genetic differentiation can occur despite high levels of migration. Coupled with a “new” available habitat created by conversion of 89% of the historic Murray estuary into a permanent freshwater ecosystem, this “stepping stone model of population structure” could have resulted in differentiation of existing central stock golden perch into the distinct Lakes stock over the short intervening period. Golden perch from the Lakes stock have not been found above Renmark. The presence of separate stocks of golden perch in the lower Murray River and Lower Lakes is supported by differences in the age structures of golden perch between these locations (Ye 2005; Mayrhofer 2007).

1.4.10 Migration

Both young and adult golden perch can undertake extensive upstream migrations, primarily between spring and mid-autumn, when stimulated by river flow, possibly related to spawning behaviour (Mallen-Cooper 1996; O'Connor et al. 2005). For example, a long-term tagging study indicated that several adult fish travelled >1000 km, averaging 10 km.day^{-1} (Llewellyn 1983; Reynolds 1983). Genetic studies, however, suggest that such large-scale movements are relatively rare (Keenan et al. 1995). Long-distance upstream migrations of larger fish appear to be related to sexual maturity (Reynolds 1983; Battaglene 1991). More recently it has been shown that juveniles make up the bulk of fish moving upstream within the Murray-Darling river system (Mallen-Cooper 1994a). These fish migrate upstream during small rises in river levels mostly at dawn and dusk which appears to concentrate spawning fish and disperse young fish into new habitats (Mallen-Cooper 1996). This is considered a reproductive strategy to compensate for the downstream distribution of the eggs and larvae (Reynolds 1983; Battaglene and Prokop 1987).

Reynolds (1983) proposed that post-spawning fish may disperse gradually during low river flows. Similarly, fishers have reported large numbers of golden perch moving downstream during periods of slack water (Cadwallader 1977a). Radio tracking has indicated that golden perch are highly mobile in the upper reaches of the Murray River for much of the year, moving both upstream and downstream (Koehn and Nicol 1998).

Movement of golden perch in the Murray-Darling river system has been impeded by numerous dams and weirs (Mallen-Cooper 1989; Jackson and Jenkins 1996; Baumgartner 2007). However, when submerged low weirs may provide some passage for fish movement (Mallen-Cooper 1993). For example, natural populations of golden perch have disappeared from the upper River Murray following the construction of the Hume Dam and Yarrawonga Weir (Lake 1971). In the streams of coastal south-eastern Australia half of the aquatic habitat has been obstructed by man-made barriers (Harris 1984). Unimpeded passage of native fish within waterways is essential for the sustainability of stocks (Jackson and Jenkins 1996). Studies indicate that both adult and juvenile golden perch readily use well-designed fishways (Mallen-Cooper 1996; Stuart and Berghuis 2002; Baumgartner et al. 2008). Adult fish can pass through slots of a vertical-slot fishway when water is flowing at 1.8 $m.sec^{-1}$ or less (Mallen-Cooper 1994b) whereas juveniles are relatively weaker swimmers (Mallen-Cooper 1994a).

1.4.11 Restocking

The natural range and abundance *M. ambigua* has declined (Lake 1971; Cadwallader et al. 1984; Rowland 1996b). Routine large-scale hatchery production of *M. ambigua* was developed in the 1980s (Gooley and Rowland 1993; Rowland 1996a). Large numbers of juvenile fish are produced in government and private hatcheries for stocking of impoundments, lakes and farm dams throughout eastern Australia (Rowland et al. 1983; Cadwallader 1985; Battaglene and Prokop 1987). Government controls have been placed on the translocation and introduction of golden perch into stream systems. Such controls are necessary because of the risks of damage to genetically distinct wild populations that could result from mass stocking, as well as the risk of disease transfer (Harris and Gehrke 1994).

2 FISHERY STATISTICS

In South Australia licence holders in the Lakes and Coorong Fishery (LCF) have access to golden perch in the Lower Lakes which comprise Lakes Alexandrina and Albert.

2.1 Total annual catches

Annual commercial catches of golden perch were below 40 t from 1984-85 to 1991-92 then increased steeply to an historical peak of 206.4 t in 1994-95. Catches subsequently declined to 36.3 t in 2001-02 then increased to a second smaller historical peak of 151.9 t in 2006-07. After 2006-07 catches declined to 49.2 t in 2009-10, before increasing to 67.4 t in 2010-11. Almost all commercial catches of golden perch (>99.7%) were taken with large mesh gill nets.

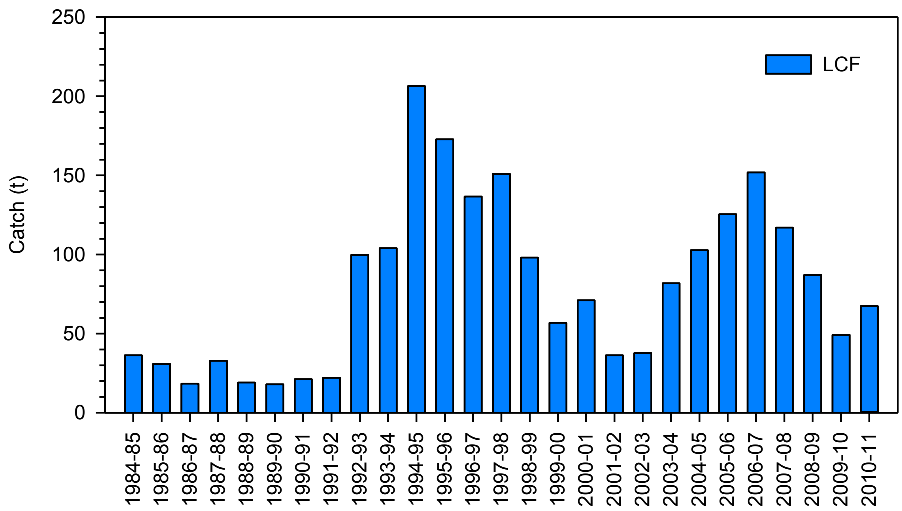

Figure 2-1. Annual catches of golden perch from the Lower Lakes.

2.1.1 Intra-annual trends in total catch

Although golden perch are typically caught throughout the year, catches vary seasonally. From 2006-07 to 2008-09 summer-autumn (December to Mar) months contributed proportionally more to the annual catches than other months (Figure 2-2). During 2010-11, catches during winter contributed proportionally more to the annual catches than in previous years.

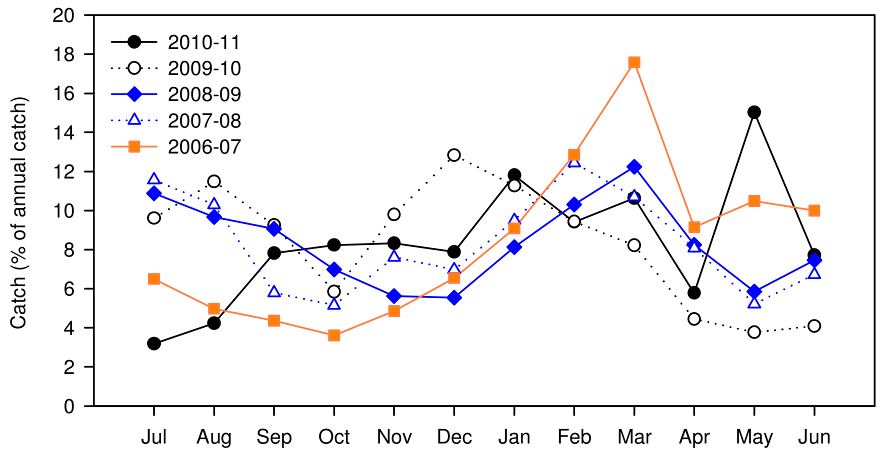

Figure 2-2. Monthly catches of golden perch in the Lakes and Coorong Fishery from 2006-07 to 2010-11.

2.1.2 Spatial distribution of catches.

Most catches were from Lake Alexandrina (long-term average (±SE) 94±1.2%) with the remainder from Lake Albert (Figure 2-3). Small catches reported from areas other than the Lower Lakes (<0.3%) were likely reporting errors.

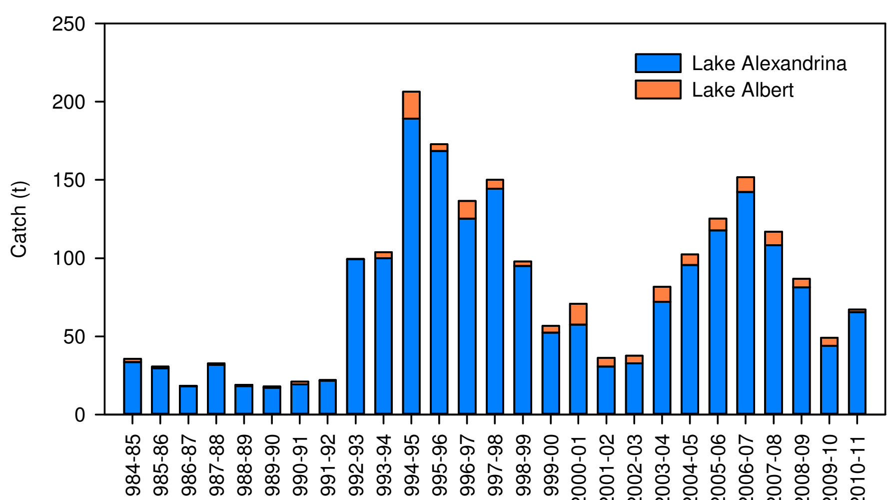

Figure 2-3. Spatial distribution of annual catches of golden perch from the Lakes and Coorong Fishery.

2.2 Lake Alexandrina – Catch, Effort and CPUE

2.2.1 Comparison of effort measures

Three measures of total annual fishing effort were available for large mesh gill nets used by the LCF in Lake Alexandrina: (i) days, (ii) fisher days, and (iii) number of nets. The first measure (days) is the number of days fished. The second measure (fisher days) is the number of individuals engaged in fishing, multiplied by the number of days fished. The third measure (nets) represents the number of nets set.

Targeted catches from Lake Alexandrina comprised 69% (5-year average 2006-07 to 2010-11) of catches and followed the same temporal trends as total catch. Targeted effort and targeted catches also had similar temporal trends (Figure 2-4 A, B). There was a linear relationship between target catch and effort (fisher days) (linear regression, LR: r^2=0.79, $F_{1,25}$=94.25, p<0.001). Similarly, catch was linearly related to (i) effort in units of days (LR: r^2=0.83, $F_{1,25}$ = 123.62, p<.001), and (ii) effort in units of net days (LR: r^2=0.79, $F_{1,25}$=93.16, p<0.001).

All three measures of effort show similar trends over time. The trend for fisher days was similar to that for days (Pearson Correlation Co-efficient, CC: r=0.99, p<0.001). Similarly, the trend in net days reflected that of fisher days (CC: r=0.98, p<0.001).

Temporal patterns in effort

Targeted effort increased from an historic low of 1,084 fisher days in 1989-99 to an historic peak of 10,585 fisher days in 1997-98 (Figure 2-4 B). Effort then declined to 3,688 fisher days in 2002-03 before increasing to 8,908 fisher days in 2006-07. Following this, targeted effort declined to 3,715 fisher days in 2009-10 then increased to 5,071 fisher days in 2010-11.

2.2.2 Catch-per-unit effort (CPUE)

Comparison between CPUE estimates

Estimates of CPUE were available for each of the measures of effort: days, fisher days and net days (Figure 2-4 C). The temporal trend for each estimate of CPUE was similar with peaks in 1994-95 and 2006-07. CPUE (kg.fisher day^{-1}) was similar to (i) CPUE (kg.day^{-1}) (CC: r=0.99, p<0.001) and (ii) CPUE (kg.net^{-1}) (CC: r=0.97, p<0.001).

Temporal trends in CPUE

CPUE (kg.fisher day^{-1}) increased from 2.3 to 13.1 kg.fisher day^{-1} between 1991-92 and 1992-93 (Figure 2-4 C). CPUE declined to 4.9 kg.fisher day^{-1} in 1999-00 and subsequently increased to a second historical peak of 12.6 kg.fisher day^{-1} in 2006-07. Following this second peak CPUE declined to 6.4 kg.fisher day^{-1} in 2009-10 (LR: r^2=0.93, $F_{1,3}$=35.594, p<0.008). In 2010-11, CPUE was 6.5 kg.fisher day^{-1}.

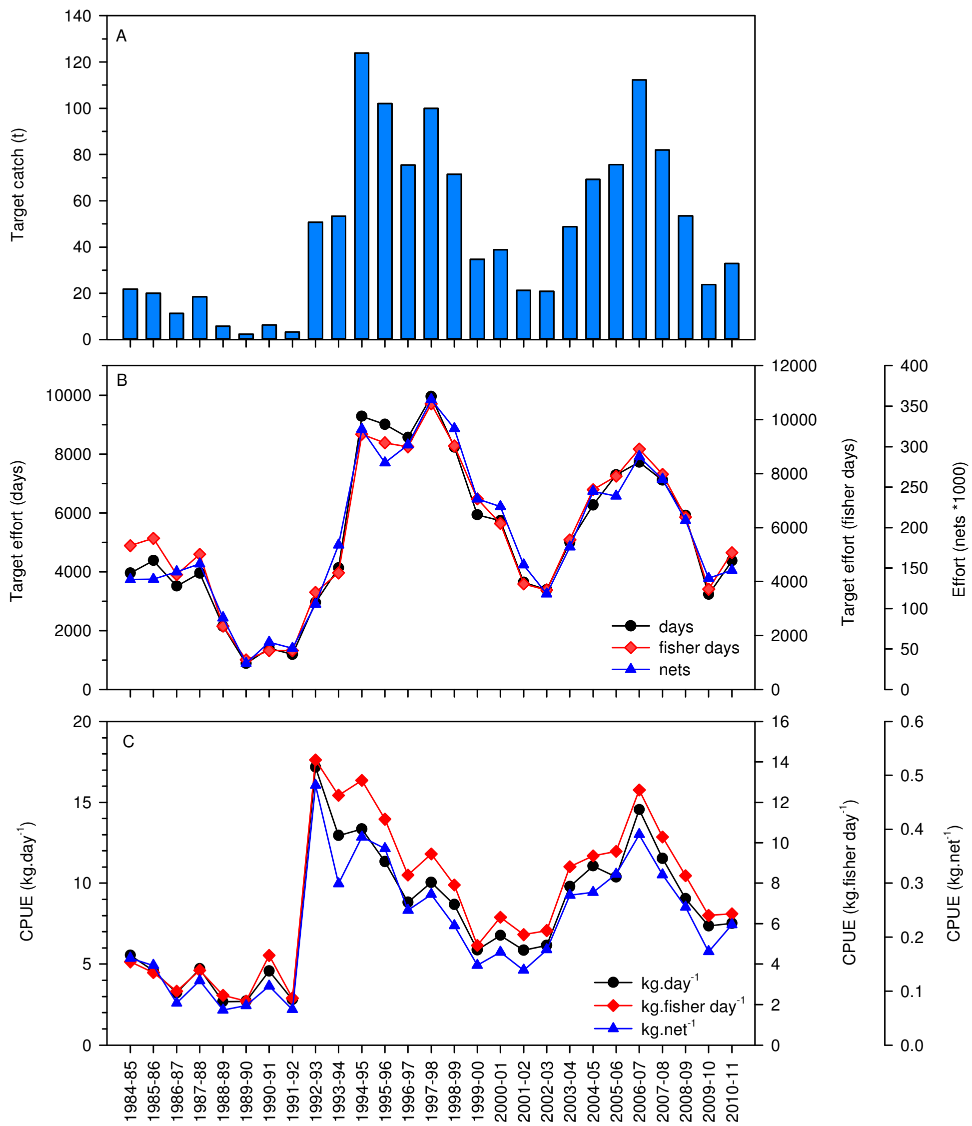

Figure 2-4. Fisheries statistics for golden perch taken by the Lakes and Coorong Fishery from Lake Alexandrina. (A) targeted catch (large mesh gill net), (B) three measures of effort, and (C) CPUE estimated from three measures of effort.

2.3 Lake Albert – Catch, effort and CPUE

Catch and effort data for targeted catches of golden perch from large mesh gill nets in Lake Albert were submitted by less than 5 licence holders in 12 of 26 years. To protect the confidentiality of licence holders all estimates of catch, effort and CPUE are presented as a proportion of the estimate from 2000-01.

2.3.1 Comparison of Effort Measures

Targeted catches comprised 38% (5-year average 2006-07 to 2010-11) of catches from Lake Albert and were highly variable among years. Similar to Lake Alexandrina, targeted effort and catches in Lake Albert had similar temporal trends (Figure 2-5 A, B). There was a linear relationship between catch and effort (fisher days) (LR: r^2=0.92, $F_{1,25}$=292.431, p<0.001). Similarly, catch was linearly related to (i) effort in units of days (LR: r^2 = 0.90, $F_{1,25}$=235.989, p<0.001), and (ii) effort in units of net days (LR: r^2=0.90, $F_{1,25}$=216.266, p<0.001).

All three measures of effort show similar trends over time. The trend for fisher days was similar to that for days (Pearson Correlation Co-efficient, CC: r=0.99, p<0.001). Similarly, the trend in net days reflected that of fisher days (CC: r=0.99, p<0.001).

Temporal Patterns in Effort

Targeted effort for using large mesh gill nets in Lake Albert was highly variable among years. Historical peaks in effort occurred in 1996 and 2000-01 (Figure 2-5 B). Following this there was a general decline in effort to 2006-07, then an increase to a minor peak in 2009-10. Effort then declined significantly to 2010-11.

2.3.2 Catch-per-unit effort (CPUE)

Comparison between CPUE estimates

Estimates of CPUE were available for each of the 3 measures of effort: days, fisher days and net days (Figure 2-5 C). CPUE (kg.fisher day^{-1}) was similar to (i) CPUE (kg.day^{-1}) (CC: r=0.99, p<0.001) and (ii) CPUE (kg.net day^{-1}) (CC: r=0.99, p<0.0001). All estimates of CPUE showed high variability among years.

Temporal trends in CPUE

CPUE (kg.fisher day^{-1}) was historically high in 1994-95, 2003-04 and 2007-08 to 2009-10. CPUE was historically low in 1982-83 and 1998-99. CPUE also declined steeply from the peak in 2009-10 to a historical low in 2010-11. It is important to note that very low levels of effort occurred in several years from 1988-89 to 1992-93.

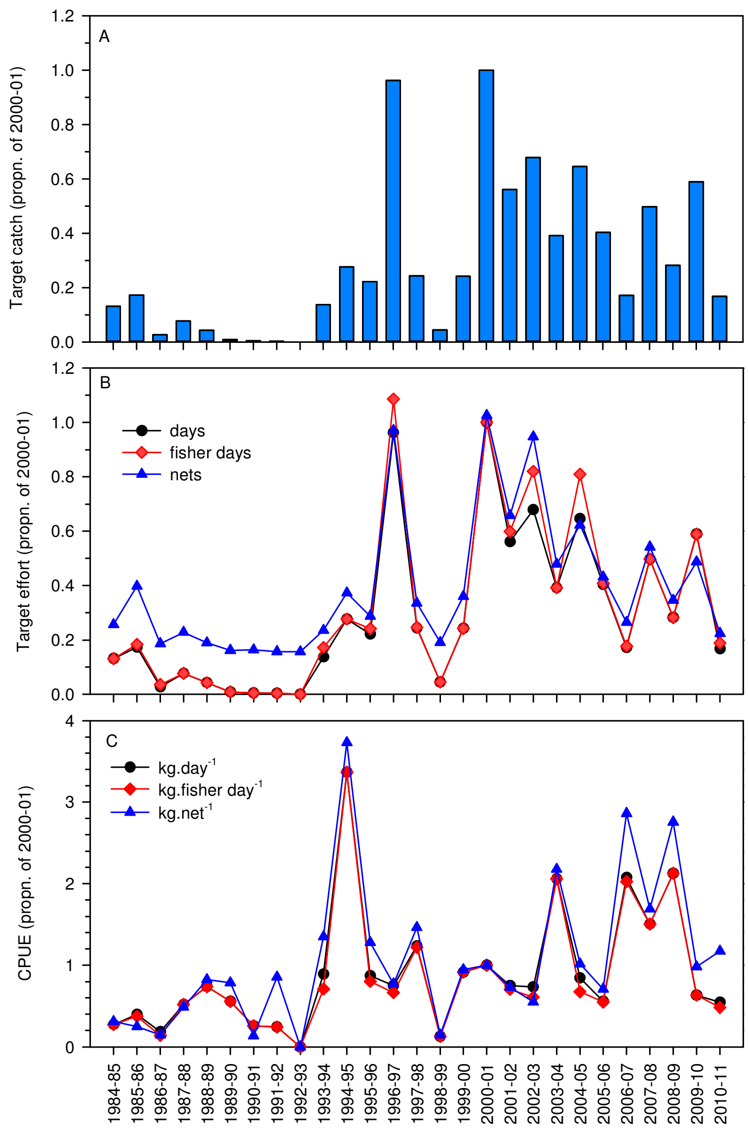

Figure 2-5. Fisheries statistics for golden perch taken by the Lakes and Coorong Fishery from Lake Albert. (A) targeted catch (large mesh gill net), (B) three measures of effort, and (C) CPUE estimated from three measures of effort.

In 2010-11 there were 37 licences operating in the LCF (Table 1-2). Over the last 5 years the number of active licence holders reporting catch of golden perch ranged from 24 in 2008-09 and 2009-10 to 30 in 2007-08.

Table 2-1. The number of Lakes and Coorong commercial licences against which catches of golden perch were reported during the last five years.

Year	No licences reporting catches of golden perch
2006-07	29
2007-08	30
2008-09	24
2009-10	24
2010-11	26

3 AGE AND SIZE STRUCTURES

3.1 Introduction

Age structures have been used to assess the status of many exploited populations and have the potential to provide a robust performance indicator (PI) for the status of golden perch in South Australia.

3.2 Materials and methods

3.2.1 Age/size samples from Lake Alexandrina in 2006-07 and 2011-12

Otoliths of golden perch were available from a study in Lake Alexandrina in 2006-07 (Mayrhofer 2007). In this study commercial catch sampling was done over sixteen sampling days from October 2006 to January 2007. Catches were from the western side of Lake Alexandrina between Milang and Point Sturt (Figure 1-1). Golden perch were randomly sub-sampled (20-25 fish per sample, n=322) from large mesh gill nets (>115 mm) catches with each fish measured (Total Length, Standard Length; TL, SL, mm) and otoliths were removed for later preparation and analysis in the laboratory.

In 2011-12, a commercial catch sampling program was conducted over seven sampling days during the months from August 2011 to February 2012. All catches were from large mesh commercial gill nets that were set on the western side of Lake Alexandrina between Milang and Clayton, similar to the study in 2006-07. For each sampling day all golden perch in the catch were measured. Each fish was measured (TL, SL, nearest mm). Sagittae were removed via a cut through the ventral ex-occipital region of the skull and cleaned, dried, weighed and stored in labelled plastic bags.

3.2.2 Laboratory preparation of otoliths

The earlier study used the ‗break and burn' method for determining ages from otoliths (Ye 2005; Mayrhofer 2007). To minimise bias from underestimating older ages which may be associated with the break and burn method and to ensure consistency between sample years all otoliths were re-processed using the thin section method.

The left sagitta from each pair of otoliths was embedded in polyester casting resin, and a 500 µm thick longitudinal section was cut with a diamond blade mounted on a Gemmasta 6" (150 mm) bench top saw. Serial sections were cut and the section incorporating the otolith centre mounted on a glass microscope slide using Cyanoacrylate glue. Mounts were ground to improve visibility of the opaque bands using silicon carbide polishing paper (grades 1200 and 900) and examined on a black background under reflected light using a Leica MZ-16 dissecting microscope at 5x magnification.

Validation of the periodicity of increments formed in otoliths, which is a key requirement for estimating ages, has been done for golden perch in river habitat in New South Wales (Anderson et al. 1992b). Ages were estimated from opaque zones in each sagitta which were counted along the ventral axis of the sulcal groove. The combination of counts and completed opaque zones and edge type (wide, narrow) was used to determine the age of the individual fish on their date of capture.

3.3 Results

3.3.1 Age and size structures

Age structures from 2006-07 ranged from 4 to 10 years, with a maximum age of 10 years for males and females. The dominant mode of 6 year olds comprised 63% of the samples (Figure 3-1). A secondary mode at 10 years comprised 18% of samples.

The range of ages present in age structures from 2011-12 was significantly broader than that for 2006-07. In 2011-12, ages ranged from 3 to 22 years for females and 4 to 20 years for males (Figure 3-1). The dominant mode of 5 year olds comprised 22% of samples, while 4, 5 and 6 year olds combined comprised 50% of samples. The modal age for females occurred at 5 years (n=134), while that for males occurred at 6 years (n=37). The dominant mode of 6 year olds from the age structure in 2006-07 was not strongly represented in 2011-12. However the secondary mode of 10 year olds in the age structure from 2006-07 persisted as 15 year olds in 2011-12.

The range of sizes of golden perch from 2006-07 was 320-460 mm TL with a modal size of 340-360 mm TL (Figure 3-1). The range of sizes from 2011-12 was 320 to 540 mm TL, with a modal size of 320-340 mm TL which was slightly smaller than in 2006-07.

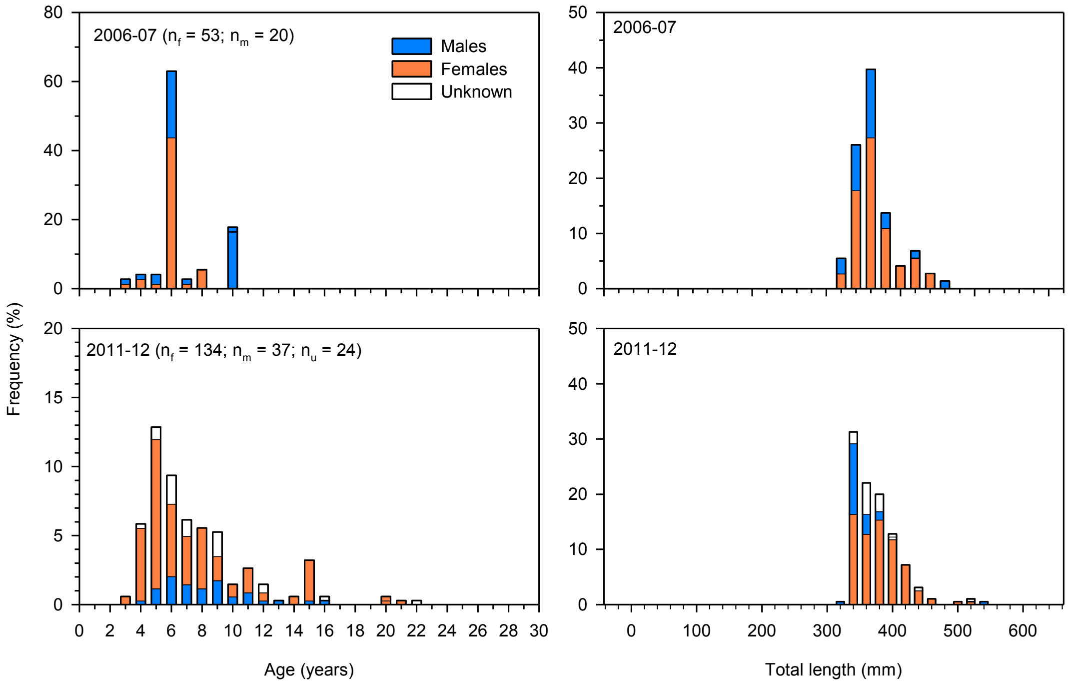

Figure 3-1. Age (left) and size structures (right) for golden perch from commercial nets in 2006-07 and 20011-12. Note different y-axis scales for ages from 2006-07 and 2011-12.

3.3.2 Sex ratios

The sex ratio (n_m:n_f) for golden perch from Lake Alexandrina in 2006-07 was 1:2.7 (n_m = 20; n_f = 53). In 2011-12, the sex ratio was 1:3.6 (n_m = 37; n_f = 134) representing a higher proportion of females in samples.

3.4 Discussion

Spawning and recruitment of golden perch in river environments is thought to occur following freshwater inflows (Ye et al. 2008; King et al. 2009). Strong year classes have been associated with high annual flows in the lower Murray River (Ye 2005; Mayrhofer 2007). In Lake Alexandrina, a strong mode of 5 year olds from commercial and research net catches in 2002 persisted as 6 year olds in commercial catches in 2003 (Ye 2005). This year class originated from 1996 which was a high flow year (8.7 GL). Age structures from research netting in 2002 also identified a secondary mode of 1 year old golden perch which originated from 2000 (n=24) which was also a relatively high flow year (4.7 GL) (Ye 2005). This mode of one year olds persisted as 6 year olds in 2006-07.

The range of ages in 2006-07 (5-10 years) was similar to that reported for age structures from 2002-03 (5-12 years) and 2003-04 (4-11 years) (Ye 2005). The maximum ages in age structures from 2002-03, 2003-04, and 2006-07 were significantly less than the reported maximum age of 26 years (Mallen-Cooper and Stuart 2003).

The age structure from 2011-12 was dominated by 5 year olds with a secondary mode of 15 year olds. The mode at 15 years was consistent with persistence of 10 year olds from the age structure in 2006-07. However, the strong mode of 6 year olds present in 2006-07 was not strongly represented in 2011-12.

The age structure from 2011-12 differed from that in 2006-07 by having: (i) a wider range of ages from 3 to 22 years, compared to 3 to 10 years in 2006-07, and (ii) a greater number of well represented age classes, compared to dominance of the age structure by a single age class in the 2006-07 sample. Consequently the age structure from 2011-12 also differed from those in 2002-03, 2003-04, and 2006-07. Such differences may be due to: (i) movement of golden perch between the lower Murray River and Lower Lakes; (ii) localised annual recruitment associated with freshwater inflows to Lake Alexandrina; (iii) impacts of fishing; and/or (iv) differences in sampling/sample sizes.

Although age structures of golden perch from Lake Alexandrina differed between 2006-07 and 2011-12, size structures were similar. Consequently, size structures are likely to be a poor indication of changes in population status with age structures providing the more robust indicator.

Age and size structures generated from thin sections of golden perch otoliths were available from a trial fish-down of carp in Lake Albert in 2009-10 (Bice 2010a). The age and size structure from Lake Albert differed to those from Lake Alexandrina. The age structure of golden perch from Lake Albert in 2009-10 ranged from 2 to 12 years with modes at 4, 5, 6, and 7 years, however the sample size was small (n=43). This range of ages was similar to that in the age structure for Lake Alexandrina in 2006-07, but not for 2011-12 when the maximum age was 22 years.

The maximum size from Lake Albert in 2009-10 (n=51) was 700 mm TL and was considerably larger than that for Lake Alexandrina in 2006-07 (440 mm TL) and 2011-12 (540 mm TL). The modal size of 460–480 mm TL from Lake Albert (Bice

2010a) was larger than that for Lake Alexandrina in 2006-07 (340-360 mm TL) or 2011-12 (320-340 mm TL) with significantly more fish in larger size classes.

The sex ratio (n_m:n_f) for golden perch from Lake Alexandrina was similar in 2006-07 (1:2.6) and 2011-12 (1:3.6). An estimate of sex ratio for golden perch was also available from a fish down trial conducted in Lake Albert in 2009-10 (Bice 2010a). The sex ratio (n_m:m_f, 2.2:1) was significantly different to that for golden perch in Lake Alexandrina in 2006-07 and 2011-12.

4 PERFORMANCE INDICATORS

4.1 Introduction

This section provides a report on the performance of the fishery for golden perch against the performance indicators (PIs) defined in the Management Plan (Sloan 2005). Reference points (RPs) are defined for each performance indicator, on the basis of historical data from 1984-85 to 2001-02 (Sloan 2005).

4.2 Performance Indicators defined in the Management Plan

4.2.1 Catch and effort based performance indicators

There are four PIs for golden perch in 2010-11. All PIs were within the range of reference points defined in the Management Plan (Sloan 2005).

Table 4-1. Performance indicators and reference points for golden perch from the South Australian Lakes and Coorong Fishery, 2010-11.

	Upper reference point	Lower reference point	2010-11	Within range of reference points
Total Catch (t)	177	20	67.4	Y
CPUE (kg.fisher day^{-1})	13	2	6.4	Y
4-year total catch trend (t.year^{-1})	56	-56	-18.7	Y
4-year CPUE trend (kg.fisher day^{-1})	4	-4	1.4	Y

4.2.2 Environmental flows

Net freshwater flow into the Coorong lagoons is also a PI in the Management Plan (Sloan 2005). Mean annual flows (MSM BIGMOD, Murray-Darling Basin Authority) are shown in Figure 4-1.

Strong year classes in age structures of golden perch in Lake Alexandrina may be related to freshwater inflows from the Murray River. Conversely, the absence of year classes in this population may be related to years of poor flow. Consequently, mean annual freshwater to Lake Alexandrina may provide an indicator of environmental conditions that impact the population of golden perch in Lake Alexandrina.

The RP associated with this PI is triggered when freshwater inflow is less than 500 GL.year^{-1} for four consecutive years as occurred between 2006-07 and 2009-10. Strong freshwater inflows occurred in 2010-11.

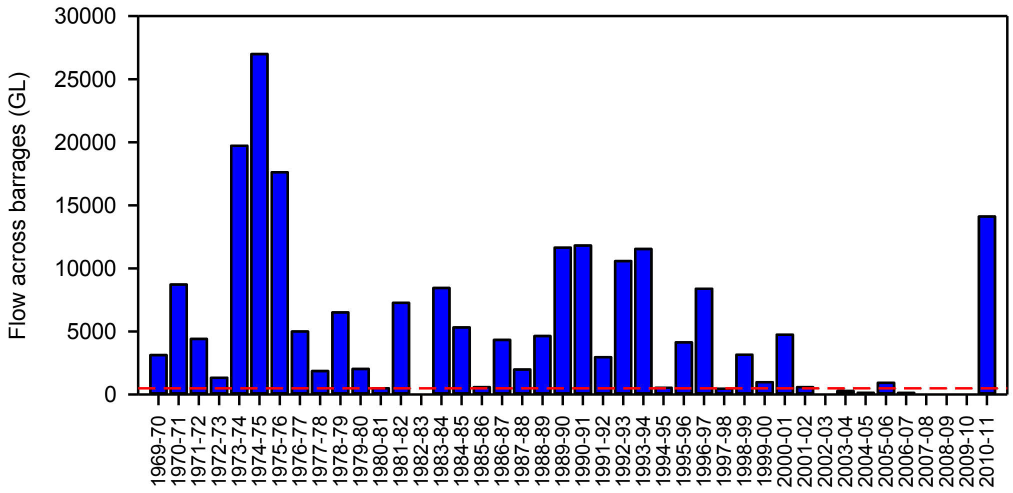

Figure 4-1. Mean annual flows across the Murray River Barrages into the Coorong lagoons between 1984-85 and 2010-11 (source MSM BIGMOD hydrological model, Murray Darling Basin Authority, 2012). Red dashes indicate RP for net freshwater flow RP.

4.2.3 Other potential performance indicators

Age structures have the potential to provide a robust PI for golden perch in Lake Alexandrina and Lake Albert. Validation of the periodicity of increments formed in otoliths, which is a key requirement for estimating ages, has been done for golden perch in New South Wales but not for South Australia (Anderson et al. 1992a).

Baseline age structures are available for Lake Alexandrina in 2011-12. Age structures for golden perch should be generated for both recreational and commercial sectors on a regular (5-yearly) basis (n>100). Appropriate sized samples may be determined from coefficient of variation of one or more age classes (Quinn and Deriso 1999). Because populations may differ across relatively small spatial scales separate age structures are required for golden perch from Lakes Alexandrina and Albert.

Size structures have been used as a PI for populations of several fish species. This method has the advantage that an age-length key can also be used to convert sizes to ages. However, because golden perch are a long-lived species (26 years) with asymptotic growth attained at approximately 8 years, high levels of error may be associated with ages assigned to sizes for older fish.

Mean annual sex ratios may indicate changes in an exploited population of fish when fishing mortality is higher for one sex compared to the other i.e. as a result of different growth rates between sexes. However, where growth rates are identical between sexes the sex ratio is unlikely to change as a result of fishing. Also sex ratios of golden perch may vary between sampling days (Mayrhofer 2007). Consequently, sex ratio is unlikely to provide a robust indicator of population health for golden perch in South Australia.

5 GENERAL DISCUSSION

5.1 Information available for assessing the status of the fishery

Assessment of the fishery for golden perch, is aided by one previous stock assessment (Ye 2005), several stock status reports (Ferguson 2006a; Ferguson 2006b; Ferguson 2008; Ferguson 2010; Ferguson 2011; Ferguson 2012), and the Management Plan for the LCF (Sloan 2005), which describes the current management arrangements, PIs and associated RPs for the fishery. Additional information is available from a study of the impacts of flow regulation, drought and fishing on exploited fishes in the Lower Murray River system (Ferguson et al. 2010).

Catch and effort data are available from South Australian Inland Waters Catch and Effort Returns from 1984-85 to 2010-11. Annual estimates of relative abundance of golden perch are provided by fishery dependent CPUE (kg. fisher day^{-1}) for this period.

Information on the presence/absence of larval and juvenile (<1 year) golden perch in river environments during recent drought and flow years is available from several studies (Cheshire and Ye 2008a; Cheshire and Ye 2008b; Ye et al. 2008; Bucater et al. 2009; Cheshire 2010; Beyer et al. 2011). Limited information on the presence of juvenile (<1 year) golden perch in the Goolwa Channel and near the barrages below Lake Alexandrina is available from several studies (Bice and Zampatti 2011; Zampatti et al. 2011; Zampatti et al. 2012).

Population age structures which can be used to provide an indication of population status were available for golden perch in Lake Alexandrina from 2002-03, 2003-04 (Ye 2005), 2006-07 (Mayrhofer 2007) and 2011-12 (this study).

5.2 Current status of the fishery for golden perch

Populations of golden perch may be vulnerable to over-exploitation because the life-history is characterised by relatively high longevity (26 years) and late maturity (females ~4 years) (Mallen-Cooper and Stuart 2003). Additionally, golden perch in the Murray River may be environmentally limited with dependence on years of high flow for establishment of strong year classes (Ye 2005; Mayrhofer 2007). The lower Murray River region experienced the worst drought in recorded history from 2002 to 2009.

Two peaks in relative abundance (CPUE) of golden perch in the Lower Lakes have occurred in the 27 years since 1984-85. High relative abundance from 1994-95 to 1997-98 likely reflects strong year classes originating from high flow in 1989-90 and early 1990s. Similarly high relative abundance in 2006-07 may reflect the presence of a year class from 2000 identified in an age structure from research nets in 2002 (Ye 2005). After the peak in 2006-07 (CPUE, kg.fisher day^{-1}) relative abundance declined to a historically low level in 2010-11, likely indicating a decline in abundance.

Although relative abundance declined, the age structure for the population of golden perch in Lake Alexandrina from 2011-12 ranged from recruitment to the fishery (3-4 years) to 22 years which is close to the maximum recorded age of 26 years (Mallen-Cooper and Stuart 2003). Additionally, more age classes were represented in the age structure from 2011-12 compared to those from 2002-03, 2003-04, and 2006-07. The differences may be due to: (i) movement of golden perch between the lower Murray River and Lower Lakes; (ii) localised annual recruitment associated with freshwater inflows to Lake Alexandrina; (iii) impacts of fishing; and/or (iv) differences in sampling/sample sizes.

In addition to this a fishery independent study found large numbers of small juvenile (<1 year old) golden perch in the barrage fish-ways below Lake Alexandrina which suggests that recruitment may have occurred in Lake Alexandrina in 2010-11 (Zampatti et al. 2012). However, it is not known if these juveniles originated from Lake Alexandrina or the Murray River.

The available information suggests that the golden perch resource in Lake Alexandrina is sustainably exploited. While the decline in CPUE over five years from 2006-07 suggests a decline in relative abundance the presence of numerous relatively strong age classes in the age structure from 2011-12 suggests that: (i) immigration of adults has occurred in conjunction with recent flooding, and/or (ii) some level of recruitment has occurred in recent years. In particular, the presence of large numbers of small (<1 year old) juveniles in fish-ways through the barrages below Lake Alexandrina in 2010-11 suggests that recruitment occurred in that year.

The population of golden perch in Lake Alexandrina would benefit from management which aims to maintain the number of age classes in age structures similar to those from 2011-12.

5.3 Uncertainty in the assessment

The most significant source of uncertainty around the PIs for the South Australian fishery for golden perch is the reliance on fishery-dependent catch and effort data. Performance indicators and reference points that are defined within the Management Plan rely on fishery dependent catch and effort with reference points restricted to a fixed time period (Sloan 2005). Further, the catch-trend and CPUE-trend PIs have widely separated upper and lower reference points that do not provide informative criteria for the accurate assessment of the status of the fishery for golden perch. Consequently, the assessment would be improved through a review of these PIs and RPs when the management plan is updated in 2013.

The only available estimate of relative abundance of golden perch is provided by estimates of CPUE from the commercial fishery. Effort measured in net days provides little advantage over using fisher days as the unit of effort because the inter-annual trend of annual targeted effort (net days) was similar to that for targeted effort (fisher days) and the two measures of effort were linearly related. Additionally, all catches from Lake Alexandrina are reported against a single reporting block.

Uncertainty also exists around levels of recreational and illegal catches. Data on recreational catches are limited to two years: 2000-01 and 2007-08 (Henry and Lyle 2003; Jones 2009). Also, golden perch is a relatively high value species but the magnitude of illegal catches is unknown.

Additional uncertainty exists around levels of incidental mortality of sub-legal sized golden perch discarded from gill nets in both commercial and recreational sectors.

Whilst age structures provide a useful indication of the status of the golden perch population in Lake Alexandrina it is important to note that they are from an exploited population that has likely also been impacted by environmental changes.

5.4 Future research needs

Commercial CPUE (kg.fisher day^{-1}) could be improved with effort reported in numbers of nets used per day, combined with net soak time and net depth. Additionally, catch and effort is currently reported for the whole of Lake Alexandrina and would be improved with finer spatial resolution. Members of the Lakes and Coorong Consultative Committee have expressed interest in improving spatial reporting of catch and effort to contribute to ongoing assessment for Marine Stewardship Certification of the fishery.

The extent and mortality of undersized golden perch discarded from commercial gill net catches, or recreational line/net catches is not known. There may also be a need for a PI based on levels of discarding, i.e. number of golden perch discarded.net day^{-1}. Inclusion of information on levels of discarding in commercial catch and effort returns is also supported by members of the Lakes and Coorong Consultative Committee to assist ongoing assessment for Marine Stewardship Certification of the fishery.

Surveys to estimate recreational harvest that are conducted on a regular basis (e.g. every five years) and which include size/age composition data would assist the assessment, and could be done in conjunction with surveys of other recreational fisheries.

Key biological knowledge gaps for the population of golden perch in Lake Alexandrina are: (i) an estimate of growth rates for male and female golden perch; (ii) a robust estimate of size/age at maturity; (iii) understanding of intra-annual trends in gonad development (12 month time series); (iv) understanding of inter-annual trends in gonad development under a range of flow/temperature conditions; (v) development of a recruitment index; (vi) understanding of spatial aspects of recruitment i.e. whether localised recruitment occurs associated with creeks which provide inflow into Lake Alexandrina (e.g. Finnis Creek, Currency Creek); (vii) the extent to which golden perch may recruit to the Lower Lakes from upstream in the lower Murray River; and (viii) dynamics of adult movement between the lower Murray River and Lower Lakes.

Other studies currently being conducted by SARDI aim to improve understanding of spawning and recruitment of golden perch in the lower Murray River: (i) a comparison of the spawning response of native fish in current high flow conditions with previous lower flow years; (ii) an assessment of the recruitment success of golden perch in relation to the 2010-11 flood and 2011-12 high flow events and in the years preceding this event.

Continued development of a time-series of age structures would provide an ongoing indication of population status for golden perch. An annual time-series of age structures of golden perch from Lake Alexandrina would allow: (i) recruitment to the fishery to be monitored; and (ii) estimation of growth rates for golden perch in Lake Alexandrina. This could be achieved by sampling commercial catches from large mesh gill nets combined with research netting using multi-panel gill nets or fyke nets. Research netting may provide an earlier indication of the presence/absence of younger fish (<1 year old) than commercial nets (3-4 years).

Validation of the periodicity of growth ring formation has not been done for golden perch in South Australia and could be achieved by: (i) marginal increment analysis of a range of year classes (~0 to 5 years) from monthly sampling; (ii) oxy-tetracycline marking of captive fish; or (iii) by a mark and release (tagging) study. A tagging study (physical/natural/trace element tags) may provide additional information on the extent of migration.

Consistency of age estimation for golden perch may be achieved by developing an otolith reference collection based on sectioned otoliths. Such a reference library would allow for age estimates to be standardised between individual researchers and between years. Additionally, the potential exists for historical age structures generated using the otolith break and burn method to be biased towards younger ages. Formal comparison of ages estimated from the break and burn method with those from thin sections is required.

REFERENCES

Anderson, J. R., A. K. Morison and D. Ray (1992a). Age and growth of Murray cod, *Maccullochella peeli* (Perciformes: Percichthyidae), in the Lower Murray-Darling Basin, using thin-sectioned otoliths. Australian Journal of Marine and Freshwater Research 43: 983-1013.

Anderson, J. R., A. K. Morison and D. J. Ray (1992b). Validation of the use of thin-sectioned otoliths for determining the age and growth of golden perch, *Macquaria ambigua* (Perciformes: Percichthyidae), in the lower Murray-Darling basin, Australia. Australian Journal of Marine and Freshwater Research 43(5): 1103-1128.

Arumugam, P. T. (1986). Importance of initial laboratory feeding for golden perch fry. The First Asian Fisheries Forum, Manila , Philippines, Asian Fisheries Society.

Arumugam, P. T. and M. C. Geddes (1987). Feeding and growth of golden perch larvae and fry (*Macquaria ambigua* Richardson). Transactions of the Royal Society of South Australia 111: 59-65.

Arumugam, P. T. (1990). A continuous flow-chamber to study prey preferences of golden perch (*Macquaria ambigua* Richardson) larvae Hydrobiologia 190(247-251).

Arumugam, P. T. and M. C. Geddes (1992). Selectivity of microcrustacean zooplankton by golden perch (*Macquaria ambigua*) larvae and fry in laboratory studies. Transactions of the Royal Society of South Australia 116(1): 29-34.

Balcombe, S. R., A. H. Arthington, N. D. Foster, M. C. Thoms, G. G. Wilson and S. E. Bunn (2006). Fish assemblages of an Australian dryland river: abundance, assemblage structure and recruitment patterns in the Warrego River, Murray-Darling Basin Marine and Freshwater Research 57: 619-633.

Battaglene, S. and F. Prokop (1987) Golden perch AGFACTS. , N.S.W. Department of Agriculture Sydney,

Battaglene, S. C. (1991). The golden perch, *Macquaria ambigua* (Pisces: Percichthyidae) of Lake Keepit, NSW. MSc, University of NSW,

Baumgartner, L. J. (2007). Diet and feeding habits of predatory fishes upstream and downstream of a low-level weir. Journal of Fish Biology 70: 879-894.

Baumgartner, L. J., C. Boys, B. P. Zampatti and I. G. Stuart (2008). Assessment of fish passage through fishways at Lock 7, 9 and 10. The Sea to Hume Dam:

Restoring Fish Passage in the Murray River'. J. Barrett. Canberra, ACT., Murray-Darling Basin Commission,: 47-60.

Beyer, K., S. Gehrig, S. J. Leigh, J. M. Nicol and B. P. Zampatti (2011) Intervention monitoring at the katarapkonative fish demonstration reach (‗Katfish Reach'), South Australia: Progress Report. SARDI Research Report Series No. 520, South Australian Research and Development Institute (Aquatic Sciences), Adelaide,

Bice, C. (2010a) Biological information and age structure analysis of large-bodied fish species captured during the Lake Albert trial fish-down, October 2009. Report to Primary Industries and Resources South Australia - Biosecurity. SARDI Research Report Series No. 430. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Bice, C. (2010b) Literature review of the ecology of fishes of the Lower Murray, Lower Lakes and Coorong. Report to the South Australian Department for Environment and Heritage. SARDI Research Report Series No. 425, South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 81

Bice, C. and B. Zampatti (2011) Response of fish to the 'Goolwa Channel Water Level Management Plan': 2009-2011. SARDI Research Report Series No. 541, South Australian Research and Development Institute (Aquatic Sciences) Adelaide, 45

Boulton, A. J. and L. N. Lloyd (1992). Flooding frequency and invertebrate emergence from dry floodplain sediments of the River Murray, Australia. . Regulated Rivers: Research and Management 7: 137-51.

Briggs, S. V. and M. T. Maher (1983). Litter fall and leaf decomposition in a river red gum (*Eucalyptus camaldulensis*) swamp. Australian Journal of Botany 31: 307-316.

Briggs, S. V., M. T. Maher and S. M. Carpenter (1985). Limnological studies of waterfowl habitat in south-western New South Wales. I. Water chemistry. Australian Journal of Marine and Freshwater Research 36: 59-67.

Brumley, A. R. (1987). Past and present distribution of golden perch *Macquaria ambigua* (Pisces: Percichthyidae) in Victoria, with reference to releases of hatchery-produced fry. Proceedings of the Royal Society of Victoria 99: 111-116.

Bucater, L., K. Cheshire and Q. Ye (2009) Fish spawning in the lower River Murray icon sites, South Australia: with reference to drought intervention. SARDI Research Report Series No. 377, SARDI Aquatic Sciences, Adelaide, 53

Cadwallader, P. L. (1977a) J. O. Langtry's 1949-50 Murray River investigations. Fisheries and Wildlife Paper, Victoria, 1-70

Cadwallader, P. L. (1978). Some causes of the decline in range and abundance of native fishes in the Murray-Darling River system. Proceedings of the Royal Society of Victoria 90: 211-224.

Cadwallader, P. L. (1979). Distribution of native and introduced fish in the Seven Creeks River system, Victoria. Australian Journal of Ecology 4: 361-385.

Cadwallader, P. L. and G. N. Backhouse (1983). A guide to the freshwater fish of Victoria Melbourne, Victorian Government Printer.

Cadwallader, P. L., G. M. Backhouse, J. P. Beumer and P. D. Jackson (1984). The conservation status of the native freshwater fish of Victoria. Victorian Naturalist 101: 112-14.

Cadwallader, P. L. (1985). Freshwater fisheries production in Australia. Australian Fisheries 44: 12-15.

Cadwallader, P. L. and B. Lawrence (1990). Fish. The Murray. N. Mackay and D. Estburn. Canberra, Murray-Darling Basin Commission: 316-335.

Cadwallader, P. L. (1977b) J. O. Langtry's 1949-50 Murray River investigations. . Fisheries and Wildlife Paper, Victoria, 1-70

Cheshire, C. (2010). Larval fish assemblages in the lower River Murray, Australia: examining the influence of hydrology, habitat and food. PhD, School of Earth and Environmental Sciences, University of Adelaide, 167

Cheshire, K. and Q. Ye (2008a) Larval fish assemblages below Locks 5 & 6, in the River Murray, South Australia from 2005 to 2007 with reference to water manipulation trials. SARDI Research Report Series No 175, South Australian Research and Development Institute (Aquatic Sciences).

Cheshire, K. and Q. Ye (2008b) Spatial and temporal variations in larval fish assemblages between Locks 1 and 6 in the River Murray, South Australia: with reference to drought intervention monitoring 2007. SARDI Research Report Series No 304, 49

CSIRO (2008) Water availability in the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Canberra, Australia, 67

Culver, D. A. and M. C. Geddes (1993). Limnology of rearing ponds for Australian fish larvae: relationships among water quality, phytoplankton, zooplankton, and the growth of larval fish Australian Journal of Marine and Freshwater Research 44: 537-51.

Ebner, B. C., T. Scholz and B. Gawne (2012). Golden perch *Macquaria ambigua* are flexible spawners in the Darling River, Australia. New Zealand Journal of Marine and Freshwater Research 43(2): 571-578.

Faulks, L., D. M. Gilligan and L. B. Beheregaray (2010). Clarifying an ambiguous evolutionary history range-wide phylogeography of an Australian freshwater fish, the golden perch (*Macquaria ambigua*). Journal of Biogeography 37: 1329-1340.

Ferguson, G. (2006a) The South Australian Lakes and Coorong Fishery: Fishery Stock Status Report for PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 1-13

Ferguson, G. (2006b) The South Australian Lakes and Coorong Fishery: Fishery Stock Status Report for PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 1-12

Ferguson, G. (2008) The South Australian Lakes and Coorong Fishery: Fishery Stock Status Report for PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 1-14

Ferguson, G. (2010) The South Australian Lakes and Coorong Fishery: Fishery Stock Status Report for PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 1-15

Ferguson, G. (2011) The South Australian Lakes and Coorong Fishery: Fishery Stock Status Report for PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 1-15

Ferguson, G. (2012) The South Australian Lakes and Coorong Fishery: Fishery Stock Status Report for PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 1-17

Ferguson, G. J., T. M. Ward, Q. Ye, M. C. Geddes and B. M. Gillanders (2010) Impacts of drought, flow regime and fishing on the fish assemblage in southern Australia's largest temperate estuary. Fishery Stock Assessment Report for PIRSA Fisheries. SARDI Research Report Series, South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 32

Geddes, M. C. and J. T. Puckridge (1988). Survival and growth of larval and juvenile native fish: the importance of the floodplain. Workshop on Native Fish Management, Canberra, Murray-Darling Basin Commission.

Gehrke, P. C. (1990). Spatial and temporal dispersion patterns of golden perch, *Macquaria ambigua*, larvae in an artificial floodplain environment. Journal of Fish Biology 37: 225-236.

Gooley, G. and S. Rowland (1993). Murray-Darling finfish: current developments and commercial potential. Austasia Aquaculture 7(3).

Hall, K. C., M. K. Broadhurst and P. A. Butcher (2012). Post-release mortality of angled golden perch *Macquaria ambigua* and Murray cod *Maccullochella peelii*. Fisheries Management and Ecology 19: 10-21.

Harris, J. H. (1984). Impoundment of coastal drainages of south-eastern Australia, and a review of its relevance to fish migrations. Australian Zoologist 21: 235-250.

Harris, J. H. and P. C. Gehrke (1994). Modelling the relationship between streamflow and population recruitment to manage freshwater fisheries. Australian Fisheries 6: 28-30.

Harris, J. H. and a. S. J. Rowland (1996). Australian freshwater cods and basses. Freshwater Fishes of South-eastern Australia. R. M. McDowall. Sydney, Reed Books, NSW: 1-247.

Henry, G. W. and J. M. Lyle (2003) The National Recreational and Indigenous Fishing Survey. Fisheries Research and Development Corporation, Canberra, 188

Humphries, P., A. J. King and J. D. Koehn (1999). Fish, flow and floodplains: links between freshwater fishes and their environment in the Murray Darling River system, Australia. Environmental Biology of Fishes 56: 129-151.

Jackson, P. D. and M. Jenkins (1996). Barriers to fish migration. Proceedings of the 1995 Riverine Environment Research Forum, Attwood Victoria, Murray Darling Basin Commission.

Jenkin, G. K. (1979). Conquest of the Ngarrindjeri. Adelaide, Rigby Ltd.

Jones, K. and A. M. Doonan (2005) 2000-01 National Recreational and Indigenous Fishing Survey: South Australian Regional Information. Primary Industries and Resources South Australia, Adelaide, 1-99

Jones, K. (2009) 2007/08 South Australian Recreational Fishing Survey. South Australian Fisheries Management Series, Primary Industries and Resources South Australia, Adelaide, 1-84

Jones, W. (1974). Age determination of growth studies of four species of fish from the River Murray. B.Sc. (Hons), Zoology Department,, University of Adelaide,

Junk, W. J., P. B. Bayley and P. B. Sparks (1989). The flood pulse concept in river-floodplain systems. Canadian Special Publication of Fisheries and Aquatic Sciences 106: 110-127.

Keenan, C. P. (1994). Recent evolution of population structure in Australian barramundi, *Lates calcarifer* (Bloch): An example of isolation by distance in one dimension. Australian Journal of Marine and Freshwater Research 45: 1123-1148.

Keenan, C. P., R. J. Watts and L. G. Serafini (1995) Population genetics of golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*) and eel-tailed catfish (*Tandanus tandanus*) within the Murray-Darling basin. Final Report. MDBC NRMS Project M262, Murray-Darling Basin Commission Canberra, 113

Kimura, M. and G. H. Weiss (1964). The stepping stone model of population structure and the decrease of genetic correlation with distance. Genetics 49: : 561-574.

King, A. J., P. Humphries and P. S. Lake (2003). Fish recruitment in floodplains: the roles of patterns in flooding and life-history characteristics Candian Special Publications in Fisheries and Aquatic Sciences 60: 773-786.

King, A. J., Z. Tonkin and J. Mahoney (2009). Environmental flow enhances native fish spawning and recruitment in the Murray River, Australia. River Research and Applications 25: 1205-1219.

Knight, M. A., A. Tsolos and A. M. Doonan (2001) South Australian Fisheries and Aquaculture Information and Statistics Report. South Australian Research and Development Institute, Adelaide, 69

Knight, M. A. and A. Tsolos (2012) South Australian Wild Fisheries Information and Statistics Report 2010/11 SARDI Research Report Series No. 612, South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 57

Koehn, J. D. and W. G. O'Connor (1990) Biological information for management of freshwater fish in Victoria. Government Printer, Melbourne, 1-165

Koehn, J. D. and S. Nicol (1998). Habitat and movement requirements of fish. Proceedings of 1996 Riverine Environment Forum, Brisbane, Queensland, Murray-Darling Basin Commission, Canberra.

Lake, J. S. (1967a). Rearing experiments with five species of Australian freshwater fishes. II. Morphogenesis and ontogeny. Australian Journal for Marine and Freshwater Research 18: 55-73.

Lake, J. S. (1967b). Rearing experiments with five species of Australian freshwater fishes. I. Inducement to spawning. Australian Journal for Marine and Freshwater Research 18: 137-53.

Lake, J. S., Ed. (1967c). Principal fishes of the Murray-Darling River system. Australian Inland Waters and Their Fauna. Canberra, Australian National University Press.

Lake, J. S. (1971). Freshwater Fishes and Rivers of Australia. . Sydney, Thomas Nelson.

Lake, J. S. (1967d). Rearing experiments with five species of Australian freshwater fishes. I. Inducement to spawning. Australian Journal for Marine and Freshwater Research 18: 137-53.

Leigh, S. J. and B. P. Zampatti (2012) Chowilla Icon Site - Fish Assemblage Condition Monitoring 2011. SARDI Research Report Series No. 597, South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 31

Lester, R. E. and P. G. Fairweather (2009). Modelling future conditions in the degraded semi-arid estuary of Australia's largest river using ecosystem states. Estuarine, Coastal and Shelf Science 85: 1-11.

Llewellyn, L. C. and M. C. MacDonald (1980). Family Percichthyidae. Australian freshwater basses and cods. Freshwater Fishes of South-eastern Australia. R. M. McDowal. Sydney: 142-149.

Llewellyn, L. C. (1983). The distribution of fish in New South Wales. Australian Society for Limnology Special Publication 7: 1-23.

Mackay, N. J. (1973). Histological changes in the ovaries of the golden perch, Plectroplites ambiguus, associated with the reproductive cycle. Australian Journal of Marine and Freshwater Research 24: 95-101.

Maher, M. T. and S. M. Carpenter (1984). Benthic studies of waterfowl breeding habitat in south-western New South Wales. II. Chironomid populations. Australian Journal of Marine and Freshwater Research 35: 97-110.

Mallen-Cooper, M. (1989). Fish passage in the Murray-Darling Basin. Proceeding of the Workshop on Native Fish Management. Canberra, Murray-Darling Basin Commission**:** 123-35.

Mallen-Cooper, M. (1993). Habitat changes and declines of freshwater fish in Australia: what is the evidence and do we need more? Sustainable Fisheries Through Sustaining Fish Habitat, Victor Harbor, South Australia, Australian Society for Fish Biology Workshop.

Mallen-Cooper, M. (1994a). How high can a fish jump? . New Scientist 142(1921): 32-37.

Mallen-Cooper, M. (1994b). Swimming ability of adult golden perch, *Macquaria ambigua* (Percichthyidae), and adult silver perch, *Bidyanus bidyanus* (Teraponidae), in an experimental vertical-slot fishway. Australian Journal of Marine and Freshwater Research 45: 191-198.

Mallen-Cooper, M. (1996). Fishways and freshwater fish migration in south-eastern Australia. PhD, University of Technology, 377

Mallen-Cooper, M. and I. G. Stuart (2003). Age, growth, and non-flood recruitment of two potamodromous fishes in a large semi-arid / temperate river system. River Research and Applications 19(7): 697-719.

Mayrhofer, M. (2007). Comparison of the life history and population biology of glden perch, *Macquaria ambigua* (Richardson 1845) (Perciformes: Perchthyidae) Honours, School of Earth and Environmental Sciences, University of Adelaide, 70

McDonald, C. M. (1978). Morpholohgical and biochemical systematics of Australian freshwater and estuarine percichthyid fishes. Australian Journal of Marine and Freshwater Research 29(5): 667-698.

MDBC (2008) River Murray system drought update number 15. Murray-Darling Basin Commission, Canberra, Australia,

Merrick, J. R. and G. E. Schmida (1984). Australian freshwater fishes, biology and management. Netley , South Australia, Griffin Press Ltd.

Merrick, J. R. M., S. H. (1985). Note on the winter diet of golden perch (Macquaria ambigua) in Queensland. . Proceedings of the Royal Society of Queensland 96: 61-62.

Musyl, M. K. and C. P. Keenan (1992). Population genetics and zoogeography of Australian freshwater golden perch, *Macquaria ambigua* (Richardson 1845) (Teleostei: Percichthyidae) and electrophoretic identification of a new species from the Lake Eyre Basin. Australian Journal of Marine and Freshwater Research 43: 1585-1601.

O'Connor, J. P., D. J. O'Mahony and J. M. O'Mahony (2005). Movements of Macquaria ambigua, in the Murray River, south-eastern Australia. Journal of Fish Biology 66: 392-403.

Pierce, B. E. (1995). Coorong and Murray Mouth Fish and Fisheries. Proceedings of the Murray Mouth Biological Resource Assessment Workshop, Adelaide, South Australian Research and Development Institute.

Pierce, B. E. and A. M. Doonan (1999) A summary report on the status of selected species in the River Murray and Lakes and Coorong fisheries. SARDI Aquatic Sciences, Adelaide, 1-14

Pollard, D. A., L. C. Llewellyn and R. D. J. Tilzey (1980). Management of freshwater fish and fisheries. An Ecological Basis for Water Resource Management. W. D. Williams. Canberra, Australian National University Press: 227-270.

Puckridge, J. T. and K. F. Walker (1990). Reproductive biology and larval development of a gizzard shad, *Nematalosa erebi* (Gunther) (Dorosomatinae: Teleostei), in the River Murray, South Australia. Australian Journal of Marine and Freshwater Research 41: 695-712.

Quinn, T. J., II, and R. B. Deriso (1999). Quantitative Fishery Dynamics. New York., Oxford University Press.

Reynolds, L. F. (1976). Decline of native fish species in the River Murray. SAFIC 8: 19-24.

Reynolds, L. F. (1983). Migration patterns of five fish species in the Murray-Darling river system. Australian Journal of Marine and Freshwater Research 34: 857-871.

Rowland, S. J., J. Dirou and P. Selosse (1983). Production and stocking of golden perch and silver perch in N.S.W. Australian Fisheries 42(9): 24-28.

Rowland, S. J. (1992). Diet and feeding of Murray cod (*Maccullochella peelii*) larvae. Proceedings of the Linnean Society of N.S.W 113(4): 193-201.

Rowland, S. J. (1996a). Development of techniques for the large-scale rearing of the larvae of the Australian freshwater fish golden perch, *Macquaria ambigua* (Richardson, 1845). Marine and Freshwater Research(47): 233-42.

Rowland, S. J. (1996b). Development of techniques for the large-scale rearing of the larvae of the Australian freshwater fish golden perch, *Macquaria ambigua* (Richardson, 1845). Marine and Freshwater Research 47: 233-42.

Sloan, S. (2005) Management Plan for the South Australian Lakes and Coorong Fishery. Primary Industries and Resources South Australia, Adelaide, 122

Stephenson, W. and E. M. Grant (1957) Experiments upon impounded golden perch or yellowbelly (*Plectroplites ambiguus*) (Richardson)) at Somerset Dam. No. 3. Ichthyological Notes Department of Harbours and Marine, Brisbane,

Stuart, I. G. and A. P. Berghuis (2002). Upstream passage of fish through a vertical-slot fishway in an Australian subtropical river. Fisheries Management and Ecology 9: 111-122.

Timms, B. V. (1989). A study of the crustacean zooplankton of six floodplain waterbodies of the lower Hunter Valley, N.S.W. Proceedings of the Linnean Society of New South Wales 110(4): 297-306.

Walker, K. F. and M. C. Thoms (1993). Environmental effects of flow regulations on the lower River Murray, Australia. Regulated Rivers: Research & Management 8(1-2): 103-119.

Ye, Q. (2005) Golden Perch (*Macquaria ambigua*). SARDI Aquatic Sciences, Adelaide, 1-24

Ye, Q., K. Cheshire and D. Fleer (2008) Recruitment of golden perch and selected large-bodied fish species following weir pool manipulation in the River Murray, South Australia. SARDI Aquatic Sciences, Adelaide, 33

Zampatti, B. P., C. M. Bice and P. R. Jennings (2011) Fish assemblage structure, movement and recruitment in the Coorong and Lower Lakes from 2006-2010. SARDI Research Report Series No. 569, South Australian Research and Development Institute (Aquatic Sciences), , Adelaide, 43

Zampatti, B. P., C. M. Bice and P. R. Jennings (2012) Fish assemblage response and fishway effectiveness at Goolwa, Tauwitchere and Hunters Creek Barrages in 2010/11. SARDI Research Report Series No. 605, South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 66