Impacts of drought, flow regime and fishing on the fish assemblage in southern Australia's largest temperate estuary

Fishery Stock Assessment Report for PIRSA

G.J. Ferguson, T.M. Ward, Q. Ye, M.C Geddes, and B.M. Gillanders

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Abstract

We analysed a 25 year time-series of fishery catch and effort data, and age/size information for four large-bodied, native fish species to investigate the hypotheses, that under conditions of reduced freshwater inflows and high fishing pressure: (i) the structure of fish assemblages in the lower River Murray system has changed, (ii) species diversity of fishes has declined, and (iii) population age structures of large-bodied, late-maturing, native fish have been truncated. Annual catch and effort in the lower Murray River system were stable for 25 years, but the proportional contribution from each of freshwater, estuarine and adjacent marine habitats, and the species within them, varied. Fish assemblages generally differed between subsequent 5-year periods, with the exception of 1989-93 when floods occurred in 4 out of 5 years, and 1994-98. Species richness declined steeply over 25 years in freshwater and estuarine habitats, and species diversity (Hill's H_2) also declined after 2001 in the estuarine habitat. Species with rapid growth and early maturation (opportunistic strategists) increasingly dominated catches while species with slow growth and late maturation (periodic opportunists) declined. Truncated population age structures suggested longevity overfishing of three periodic strategist species; golden perch (*Macquaria ambigua*), black bream (*Acanthopagrus butcheri*), mulloway (*Argyrosomus japonicus*), and a fourth species with an intermediate strategy, greenback flounder (*Rhombosolea tapirina*). This has implications for management because loss of older/larger individuals suggests reduced capacity to withstand, or recover from, deteriorating environmental conditions as the lower Murray River system experiences historically extreme drought. Management of these species should seek to preserve the remnant population age structures, then to rebuild age structures by allowing recruits to become established in the adult population. We recommend that assessment of multi-species fisheries, in changeable environments, such as occur in estuaries and other end-river environments, requires a suite of indicators that address changes in fish assemblages and populations.

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1 INTRODUCTION

Many cities are located where rivers meet the sea and estuaries are among the most degraded habitats on earth (Blaber et al. 2000; Edgar et al. 2000). Fish assemblages in freshwater, estuarine and near-shore, marine environments are commonly exposed to the combined impacts of reductions in river flows resulting from droughts and/or excessive water abstraction and intensive fishing pressure (Gillanders and Kingsford 2002; Lotze et al. 2006; Bauchbaum and Powell 2008). Changes to the scale, frequency and seasonality of flows have particularly severe impacts on species that require flood pulses for successful reproduction or larval survival (Drinkwater and Frank 1994; Griffiths 1996; Whitfield and Marais 1999; Ferguson et al. 2008).

Fishing tends to remove long-lived, slow growing species and to favour those with high turnover rates (Jennings and Kaiser 1998; Pauly et al. 1998; Jackson et al. 2001). The combination of reductions in freshwater inflows and intensive fishing pressure have been implicated as causal factors in changes to the structure of estuarine fish assemblages, including reductions in species diversity and in abundance of long-lived, slow growing species worldwide (Musick et al. 2001; Lotze et al. 2006; Bauchbaum and Powell 2008; Ecoutin et al. 2010).

Large, long-lived fishes with delayed maturation have been classified as periodic strategists (Winemiller and Rose 1992). An extended lifespan allows periodic strategists to survive long periods of sub-optimal environmental conditions while large body size, with correspondingly high fecundity, allows them to produce large numbers of progeny when environmental conditions are conducive to successful reproduction. Periodic strategists that require flood pulses for successful reproduction may be particularly vulnerable to the combined impacts of reduced flows and fishing (Griffiths 1996; Rowell et al. 2005; Ferguson et al. 2008; Rowell et al. 2008). The removal of large/old, highly fecund individuals from the population through fishing, during unfavourable environmental conditions, can reduce the capacity of periodic strategists to produce strong year classes when environmental conditions are favourable (Laë 1995; Jennings and Kaiser 1998; Beamish et al. 2006).

In contrast to periodic strategists, opportunistic strategists are characterised by reduced longevity, small body size, early maturation, small eggs, small clutches and continuous spawning (Winemiller and Rose 1992). This suite of traits increases the potential reproductive capacity (intrinsic rate of population growth) of these species and provides resilience to high rates of adult mortality due to predation or fishing pressure (Jennings and Kaiser 1998). In situations where predator populations are large, the population size of opportunistic strategists is often controlled by predation (May et al. 1979; Pimm and Hyman 1987; Blaber et al. 2000). When predation levels are reduced, the population size of opportunistic strategists commonly increases.

Mixed-species fisheries pose a particular threat to species with low productivity, because the persistent abundance of highly productive species may continue to stimulate fishing activity, even though the abundance of species with low productivity has been reduced below the level where targeted fishing is economically viable (Musick 1999). Traditionally, in mixed-species fisheries, stock assessments have tended to focus on a single species (Gulland 1987; Greenstreet and Hall 1996; Pitcher 2001; Pikitch et al. 2004). Progress towards a multi-species approach to stock assessments requires knowledge of the interacting impacts of by-catch and discarding, habitat degradation and climate change on the sustainability of exploited species along with information on the life-history of individual species (May et al. 1979; Fowler 1999; King and McFarlane 2003). Although progress has been made towards providing information for multi-species stock assessments in estuaries (Gray et al. 2005; Rotherham et al. 2006), such assessments are rare.

There have been several studies of the temporal change in fish assemblages in Australia's temperate estuaries (Loneragan and Potter 1990; Gray et al. 1996; Jackson and Jones 1999). All were based on fishery-independent data and done over a relatively short time period (<9 years). Long-term datasets that are compiled to monitor commercial fisheries may provide valuable insights into changes in the structure of estuarine fish assemblages and provide a baseline against which to assess the current status of estuarine systems and plan future management (Gulland 1987; Claro et al. 2009). In many cases, fisheries datasets provide the only information to identify species that have been impacted and to set restoration targets (Patton et al. 1998; Maki et al. 2006).

The remnant Murray River estuary is the largest estuarine system in temperate Australia and supports a fish assemblage that includes species with a wide range of life-history characteristics. Since 2002, freshwater flows into the estuary have been reduced by a severe drought combined with excessive water abstraction (Lester and Fairweather 2009). A small multi-gear, multi-species, commercial fishery targets finfish in freshwater and estuarine habitats and a bivalve species in the adjacent marine habitat. The area is also subject to significant recreational fishing because it is close to the major metropolitan centre of Adelaide (Jones 2009).

This paper investigates the influence of freshwater inflows and fishing pressure on the fish assemblages of the lower Murray River system. Analyses are based on (i) modelled freshwater flow data, (ii) a 25-year time-series of catch and effort data from the commercial fishery, and (iii) age/size information for four large-bodied, native fish species. We use these data to investigate the hypotheses, that under conditions of reduced freshwater inflows and high fishing pressure; (i) fish assemblages in the lower River Murray system have changed, (ii) species diversity of fishes has declined, and (iii) population age structures of large-bodied, late-maturing, native fish have been reduced. Implications for stock assessment of multi-species fisheries in end-of-river environments are discussed and options for mitigating the impacts of fishing are identified.

2 MATERIALS AND METHODS

2.1 Study area

The original estuary of the Murray River covered 660 km^2, and included the brackish Lakes Alexandrina and Albert, and the north and south Coorong lagoons (Figure 2-1). In 1940, five barrages were constructed between the lakes and lagoons. Habitats above and below the barrages are now respectively, freshwater and estuarine. The remnant estuary comprising the Coorong lagoons is now only 11% of its original size. Since construction of the barrages, water abstraction for irrigation has reduced mean annual flow into the estuary to 20% of natural levels and the extent and frequency of the natural spring floods has been reduced so that in some years they do not occur (Thomas 1999). Additionally, the frequency with which flow ceases at the river mouth has increased from one year in twenty to approximately one year in two (Close 1990). Marine habitat adjacent to the river mouth is high energy ocean beach.

2.2 The Lakes and Coorong Fishery

The Lakes and Coorong Fishery (LCF) is a multi-species, multi-method fishery that has had access to resources in freshwater, estuarine and adjacent marine habitats in the lower Murray River system in South Australia since 1846 (Olsen and Evans 1991). Gill nets are the primary gear used in the fishery (>95% of all catches). In freshwater, the LCF uses large mesh gill nets (>115 to ≤150 mm) to target golden perch (*Macquaria ambigua*), bony bream (*Nematalosa erebi*), and populations of the introduced species; European carp, (*Cyprinus carpio*) and redfin perch (*Perca fluviatilis*). Within the remnant estuary, large mesh gill nets accounted for 65% of effort (25 year average) and were used to target juvenile mulloway, (*Argyrosomus japonicus*), black bream (*Acanthopagrus australis*), and greenback flounder (*Rhombosolea taparina*). Small mesh gill nets (>50 to ≤64 mm), which accounted for the remaining estuarine effort were used to target yellow-eye mullet (*Aldrichetta forsteri*). In the adjacent marine habitat adult mulloway were targeted using large mesh gill nets and pipi (*Donax deltoides*), a bivalve which is collected manually using cockle rakes.

Recent management of the Lakes and Coorong Fishery has been through a mixture of input and output controls. Since the early 1980's input controls have included limited-entry (36 licences in 2006), with gear entitlements and owner-operator provisions applied to licences. Gear restrictions apply to numbers of nets, net dimensions and mesh sizes. Output controls include legal minimum lengths (LML) for most targeted species and the fishery for pipi has been subject to quota management since 2007, although quota has failed to constrain catches (Ferguson 2010).

2.3 Data

Freshwater inflows

In this paper "inflow" refers to freshwater from the Murray River entering the estuary through the barrage system. Estimates of mean monthly freshwater inflow to the lower River Murray system were obtained from the regression-based Murray hydrological model (MSM-Bigmod, Murray-Darling Basin Commission) for the years 1962 to 2008. This suite of models uses inputs based on inflows (from rainfall and tributaries), storage volumes and outflows (including diversions and losses) to provide estimates of daily flows. Flows were aggregated into financial years because the highest monthly flows occur during late spring (August-November) and summer (December-February). The unit of freshwater flow is gigalitre.year^{-1} (GL.y^{-1}).

Fishery catches

Since 1984, fishers have been required to provide daily catch and effort data, submitted to the South Australian Research and Development Institute on a monthly basis. Fishery data available from 1984 to 2008 were: location (Figure 2-1), species, catch (kg), gear, and effort (fishing days). Data were aggregated into financial years to capture spring-summer seasonality patterns i.e. 1984 refers to 1984-85.

2.4 Analyses

Temporal trends in catch structure

To determine if the species structure of catches had changed over time, a quantitative comparison of composition of catch species among five, 5-year time periods was done using multivariate techniques. Data were aggregated over 5 years to capture periods of high, medium and low freshwater inflow. Variables were first transformed to a Euclidean distance dissimilarity matrix. Canonical Analysis of Principal Coordinates (CAP) was used to ordinate the axes (Anderson and Willis 2003). Permutational multivariate analysis of variance (PERMANOVA) (Anderson et al. 2005) was used to determine differences in species composition between 5-year periods. For all CAP and PERMANOVA tests, 4999 unrestricted random permutations of the raw data were used (Anderson 2001). A similar procedure was used to determine if the species composition of annual catches changed between low (<3,000 GL.y^{-1}), medium (3,000 to 6,000 GL.y^{-1}) and high (>6,000 GL.y^{-1}) flow years.

Temporal trends in species richness and diversity

To determine if the species diversity of fishes in the lower River Murray system had decreased over time, indices of richness and diversity were estimated from annual catch data. Hill's suite of numbers provide appropriate estimates of species richness and diversity for investigating fishery impacts on fish assemblages (Rice 2000). Species richness, (S, Hill's H_0), was estimated, and two univariate measures of diversity; Hill's N_1 and N_2 (Hill 1973) were estimated for freshwater, estuarine and marine habitats, and for all habitats combined. Hill's N_1, the exponential of the Shannon-Wiener function (exp H') is most sensitive to changes in rare species and Hill's N_2, the reciprocal of Simpson's index (1/D), is most sensitive to changes in the abundant species (Krebs 1989).

Temporal trends in fishery catch and effort

For each of the freshwater, estuarine and adjacent marine habitats, estimates of total annual catches and effort, proportional contribution of key species and catch per unit effort (CPUE) of key species were calculated. Catch per unit effort was estimated as total annual catch (kg)/total annual effort (fisher days). Estimates of catches and CPUE for mulloway were made separately for estuarine and marine habitats. Annual catches of species that were <1 t were aggregated into an 'other' category.

Trends in annual CPUE for each species were compared with trends in annual freshwater inflow using linear regression. Time lags between annual catches and inflows were determined from population age structures for golden perch, mulloway, black bream, and greenback flounder. For other species appropriate lag periods were estimated from life-history information sourced from the literature searches (Table 1).

Population life-history and demography

Age and size data were available from commercial catches of four large-bodied, native species; golden perch, (2006-07, n=98), mulloway, (2001-02, $n_{juveniles}$ = 260, n_{adults} = 73), greenback flounder, (2007-08, n = 85) and black bream, (2006-07, n = 138). Catches were intercepted at the point of landing and the total length (TL) of each fish was measured and sagittae removed via a cut through the ventral, ex-occipital region of the skull. Sagittae were cleaned, dried and stored in labelled plastic bags. Sagittae from mulloway, greenback flounder and black bream were embedded in fibreglass resin, and a longitudinal section cut with a diamond blade mounted on a Gemmasta 6" (150 mm) bench top saw. Each 500 μm thick section was cut so as to incorporate the otolith centre and then mounted on a glass microscope slide using Cyano-Acrylate glue. The mounts were examined using a Leica MZ-16 dissecting microscope with incidental light, and the ages of the fish were determined from counts of opaque zones. For golden perch, ages were determined from opaque zones in otoliths that had been broken and burned. The pattern of deposition for otoliths suggests that the opaque zone is completed in November-December for golden perch, black bream and mulloway in southern Australia (Anderson et al. 1992; Sarre 1999; Ferguson in prep). Ages for greenback flounder have not been validated.

Literature searches were conducted to locate estimates of maximum age/size, age/size at maturity, and growth rates. Searches were firstly directed at peer-reviewed articles in journals (Web of Science, December 2009), then secondly at theses and technical reports.

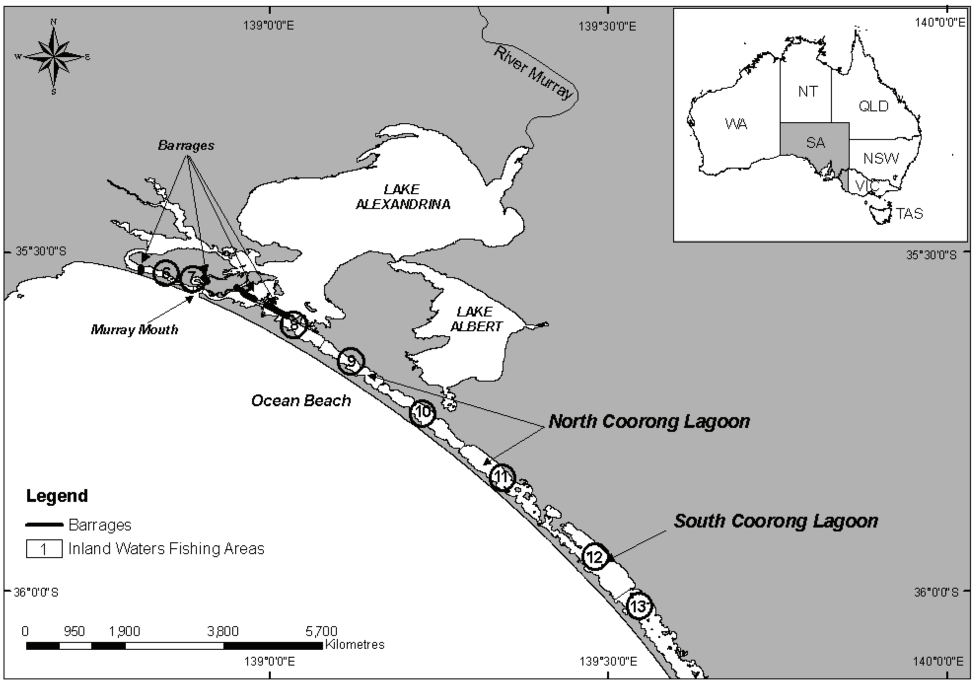

Figure 2-1 Map of lower River Murray system showing the freshwater Lakes Alexandrina and Albert, remnant estuary of the Murray River comprising the Coorong Lagoons, and the adjacent marine environment. (Inset map of Australia showing South Australia and the lower Murray River system, circled numbers are fishery catch and effort reporting areas).

3 RESULTS

3.1 Temporal trends in freshwater flows

Annual freshwater flows greater than 11,000 GL occurred in four years 1989, 1990, 1992, and 1993 within a single 5-year period (Figure 3-1A). After 1993, annual flows were generally low (<1,000 GL) with only four years experiencing flows greater than 1000 GL. When annual freshwater inflows were aggregated by five-year periods there was one period with high freshwater inflow, (1989-93), and two periods with intermediate freshwater inflow (1984-88 and 1994-98). Flows were low for the two most recent five-year periods (1999-2003 and 2004-08). Flows were highly seasonal (Figure 3-1B) with peaks in September - October for each five-year period.

3.2 Temporal trends in species structure of catches

Species structure of catches changed over time. CAP analysis of annual catches showed that the species composition could be allocated to five-year time periods with an overall classification success of 76% (Figure 3-2A). Overall species composition differed among 5-year periods (PERMANOVA, Pseudo-$F_{4,24}$ = 8.3463, p<0.001). Pairwise comparisons showed that catch composition differed among all combinations of 5-year periods (PERMANOVA, p<0.05), except for 1989-93 and 1994-98 (p>0.05). CAP analysis, constrained by high, medium, and low freshwater inflow, rather than the 5-year periods, provided less clear separation of groups (Figure 3-2B). Classification success for the low-flow grouping (< 3,000 GL.y^{-1}) was 100%, but overall classification success was 56%. Overall species composition differed between high, medium and low freshwater inflow (PERMANOVA, Pseudo-$F_{2,24}$ = 2.4733, p< 0.036). Pairwise comparison showed that catch composition differed between the low-flow years and medium, (3,000 – 6,000 GL.y^{-1}, p<0.05) and high-flow years (>6,000 GL.y^{-1}, p<0.05) but was the same between medium and high flow-years (p>0.1).

3.3 Temporal trends in species richness and diversity

The number of species (N_0) reported in all catches from each year, declined linearly from 29 species in 1985 to 16 in 2008 (y = -1.483x + 45.322, $F_{1,24}$ = 32.432, p<0.001) (Figure 3-3). This reflected declines of species richness in both freshwater (y = -2.791x + 31.647, r^2 = 0.58, $F_{1,24}$ = 32.296, p<0.001) and estuarine habitats (y = -1.570x + 30.839, r^2 = 0.33, $F_{1,24}$ = 11.503, p<0.01) but not for the marine habitat (r^2 = 0.00). Higher species richness in freshwater habitat prior to 1996 was partly due to the presence of two exotic species, rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*). Within the estuary the strongest decline occurred in the southern section which comprised the north and south Coorong lagoons (Figure 2-1, Areas 9-13), but excluded the region adjacent to the river mouth ($y = -1.358x + 30.839$, $r^2 = 0.42$, $F_{1,24} = 17.006$, $p<0.01$).

Diversity of rare species across all habitats (Hill's N_1) changed little over time (Figure 3-3). However, diversity of the most abundant species (Hill's N_2) varied between years in freshwater and estuarine habitats, but not for the marine habitat. In the freshwater and estuarine habitats, diversity of abundant species increased from 1988 to 1992, then remained stable until 2008 in freshwater habitat but declined steeply in the estuarine habitat.

3.4 Temporal and spatial trends in fishery catch and effort

All habitats

Total annual catches in the LCF increased from a minimum of 1,142 t in 1984 to between ~2,100 t and ~2,700 t from 1989 to 2008, with an average total annual catch of 2,114 $t.y^{-1}$ (± SE 79.3) (Figure 3-4A). The contribution from freshwater, estuarine, and marine habitats changed over time. Freshwater habitat contributed 70-80% to the total catch in the mid to late 1980's but this declined to 33.2% in 2001, before increasing again to 64.3% in 2008. Catches from the estuary were relatively stable with an average of 276 $t.y^{-1}$ (± SE 17.8), over 25 years contributing ~14% of the total catch. Marine habitat contributed 2.5% of the total annual catch in 1984, which increased to a peak of 55.4% in 2002, before declining to 22.8% in 2008.

Total annual effort was consistent among years and ranged from 7,343 to 10,110 days with an average of 8,643 $days.y^{-1}$ (±SE 168.4), over 25 years (Figure 3-4B). The years of lowest annual effort occurred from 2001 to 2008. The contribution from marine, estuarine, and freshwater habitats changed over time. Effort in freshwater habitat ranged from 68.8% of total effort in 1997 to 36.2% in 2002, with years of highest effort between 1993 and 1998. Effort in the estuary declined over 25 years from 53.0% of the total in 1984 to 29.6% in 2008 (LR: $y = -0.007x + 34.933$, $r^2=0.56$, $F_{1,24} =32.414$, $p<0.001$). As effort increased in the freshwater habitat (1987-1990, 1992-99, and 2002-08) there was a corresponding decline in the estuarine habitat. Effort in the marine environment increased steadily from 1% of total effort in 1984 to peak at 23% in 2006 (LR: $y = 0.14x + 0.76$, $r^2=0.94$, $F_{1,24} =170.268$, $p<0.001$).

Freshwater

In the freshwater habitat catches consisted mostly of bony bream and European carp, which together contributed >88% of the catches in all years (Figure 3-5A). The contribution of the latter species increased from 30 to 57% between 1990 and 2008, and 15 to 38% across all habitats. The contribution of bony bream declined from >65% in the mid 1980's to 34% in 2008. Golden perch contributed 7 to 10% of total annual freshwater catches.

Estuary and marine

For catches from the Murray River estuary, there was a trend of increasing dominance by the small-bodied, native yellow-eye mullet, which contributed 50 and 84% to catches in 1998 and 2008, respectively (Figure 3-5B). Juvenile mulloway contributed 18-35% of the total estuarine catch from 1993-2001, which then declined to 10% in 2007-08. Annual catches from the marine habitat were dominated by pipi (>95%) after 1986 (Figure 3-5C).

3.5 Population demography, life-history and impact of freshwater flows

High growth rates and early maturation indicated that European carp is an opportunistic strategist (Table 3-1). Relative abundance of this species increased following high freshwater inflows because variability in annual freshwater inflow explained 12% of the variation in relative abundance (Table 3-2). Relative abundance increased steeply in the early 1990's, following historically high freshwater inflows in the late 1980's (Figure 3-6).

An estimate of growth rate was not available for bony bream but low maximum age and early age of maturity indicated a likely opportunistic life history strategy (Table 3-1). Although relative abundance of bony bream increased following flooding in the late 1980's there was little inter-annual variation in relative abundance in later years (Table 3-2, Figure 3-6).

Slow growth rate, large maximum size and age, combined with high age at maturity indicated that the perchichthyid golden perch had a periodic strategist life history (Table 3-1). Although a strong increase in relative abundance occurred in 1993 following flooding, there was no relationship between annual freshwater inflows and relative abundance (Figure 3-6, Table 3-2). Ages ranged from 3 to 10 years with a mode of 5 years, that corresponded to a year class that originated in 2003 (Figure 3-7). The maximum age of fish was 10 yrs suggesting that the age distribution has been truncated given this species may live to 26 years (Table 3-1).

The life-history of yellow-eye mullet is characterised by rapid growth, high fecundity, early maturation and a maximum age of 4-7 years indicating an opportunistic life-history strategy (Table 3-1). It is likely that relative abundance of yellow-eye mullet from the Murray River estuary has increased because annual estimates of CPUE have increased whilst catches have remained stable over 25 years (Figure 3-5, 3-6). Variability in annual freshwater inflow to the estuary explained 45% of the variation in relative abundance (Table 3-2), with high annual freshwater inflow associated with low CPUE (Figure 3-8).

The life-history of the periodic strategist mulloway is characterised by slow growth, late maturation and high maximum age (Table 3-1). Mean annual flow explained 16% of the variation in CPUE for adults in the marine habitat (Table 3-2). Increasing CPUE for juvenile mulloway

(<812 mm TL, Table 3-1) from 2001 should be interpreted with caution because the area fished contracted with decreasing freshwater inflow (Figure 3-8). The ages of juveniles in the estuary ranged from 0 to 6 years with a mode of 3 years (Figure 3-7). Age structures of adults from marine habitat were truncated because few individuals (4%) were >16 years old, which was 60% below the maximum age of 41 years (Figure 3-7, Table 3-1).

The life history of the periodic strategist black bream is characterised by slow growth, intermediate age of maturity and high fecundity (Table 3-1). Although CPUE increased over 20 years (Figure 3-6) this should be interpreted with caution because catches: (i) declined precipitously in the early 1980's and subsequently remained low (Figure 3-5); and (ii) appeared to contract spatially with decreasing freshwater inflows (Figure 3-8). Ages for black bream ranged from 3 to 18 years with modes at 3 and 9 years corresponding to year classes from 2003 and 1998 (Figure 3-7). The maximum age of 29 years (Table 3-1), and presence of few individuals >11 years old (<7%), indicated that the age distribution was truncated. The legal minimum length (LML) for black bream is 46% above size of maturity (SOM).

Little is known of the life-history of the pleuronectid greenback flounder in the Murray River estuary. This species is possibly intermediate between opportunist and periodic strategist because individuals are thought to grow quickly, to mature at approximately one year old, and to be highly fecund, but may attain >6 years age (Table 3-1). Catches and relative abundance declined steeply from 2000 (Figures 3-5, 3-6). Age structures from commercial catches were dominated by one and two year old females (>93%), although the maximum age was likely >6 years (Figure 3-7, Table 3-1).

The r-strategist (MacArthur and Wilson 1967) life-history of pipi is characterised by fast growth, early maturation, and a short life span of 3-5 years (Table 3-1). Variability in freshwater flows explained 45% of variability in relative abundance of pipi (Table 3-2).

Table 3-1. Life history parameters for species in three habitats in the lower River Murray; F = freshwater, E = estuarine, M = adjacent marine, AOM = age of maturity, SOM = size of maturity. Max size is the von Bertalanffy growth parameter L_{inf}, where available.

Species	Habitat	Max Age (y)	*Max size (mm)*	*K*	AOM (y)	SOM (mm)	Source
Golden perch *Macquaria ambigua*	F	26	-	0.25 - 0.45	4-5	F/M 400	(Anderson et al. 1992)
European carp *Cyrinus carpio)*	F	32	1200	0.38 - 0.48	1.4-2.7	F 273-328 M 287-307	(Vilizzi and Walker 1999; Smith 2005)
Bony bream *Nematalosa erebi*	F	~3	480	-	1-2	F 108 M 121	(Puckridge and Walker 1990)
Murray cod *Maculolella peeli*	F	48	1200	0.11	M 3-4 F 4-6	F 500 M 400	(Anderson et al. 1992; Gooley et al. 1995)
Mulloway *Argyrosomus japonicus*	M & E	41	1600	0.16 - 0.14	5	F/M 812	Ferguson, in prep.
Black bream *Acanthopagrus butcheri*	E	29	540	0.04 - 0.08	1.9 - 4.3	F/M 129-169	(Coutin et al. 1997; Morison et al. 1998; Norriss et al. 2002)
Greenback flounder *Rhombosolea tapirina*	E	6	-	-	~1	F 219 M 190	(Kurth 1957; Crawford 1986; Stevens et al. 2005)
Yellow-eye mullet *Aldrichetta forsteri*	M & E	4-7	500	-	2	F/M 220-230	(Harris 1968)
Pipi *Donax deltoides*	M	4	-		1	F/M 36	(King 1976)

Table 3-2. Linear regressions performed on CPUE for species in three habitats in the Lakes and Coorong Fishery. For *Argyrosomus japonicus* (a = adults, j = juveniles). For the independent variable the subscript (L) is the time-lag in years. The coefficients of determination (r^2) are shown with their *P* values (*significant, α=0.05, ^{ns}non significant).

			Regression statistics			
Habitat	Species	Independent variable	b (±SE)	$F_{1,24}$	r^2	*p*
Freshwater	European carp *Cyprinus carpio*	$flow_{L-2}$	4.51 (2.571)	3.079	0.12	0.073^{ns}
	Golden perch *Macquaria ambigua*	$flow_{L-5}$	-0.03 (0.311)	0.013	0.00	0.910^{ns}
	Bony bream *Nematalosa erebi*	flow	-1.04 (0.997)	1.106	0.05	0.304^{ns}
Estuary	Black bream *Acanthopagrus butcheri*	$flow_{L-3}$	-0.65 (0.234)	7.732	0.25	0.011*
	Greenback flounder *Rhombosolea tapirina*	$flow_{L-1}$	0.19 (0.414)	0.215	0.01	0.647^{ns}
	Mulloway *Argyrosomus japonicus* (j)	$flow_{L-3}$	0.12 (0.627)	0.040	0.00	0.844^{ns}
	Yellow-eye mullet *Aldrichett forsteri*	$flow_{L-1}$	-4.89 (1.135)	18.563	0.45	0.000**
Marine	Mulloway *Argyrosomus japonicus* (a)	$flow_{L-5}$	2.35 (1.142)	4.250	0.16	0.051^{ns}
	Pipi *Donax deltoides*	flow	60.39 (13.802)	19.149	0.45	0.000**

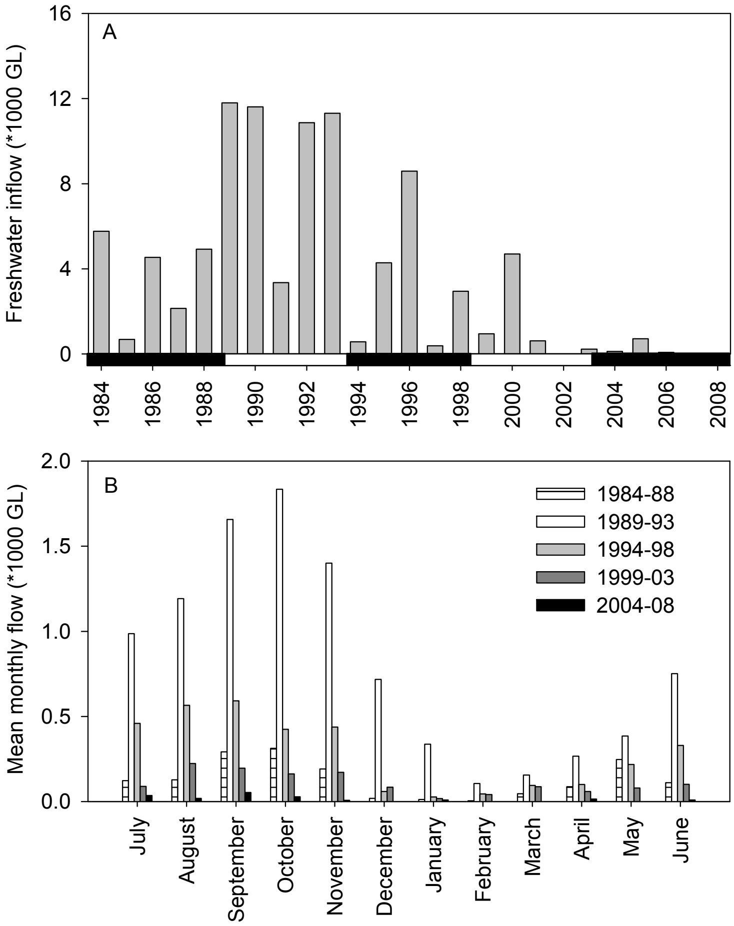

Figure 3-1. (A) Mean annual freshwater inflows to the Lower Lakes and Murray River estuary (black and white bars show five-year periods), and (B) mean monthly freshwater inflows for each five-year period.

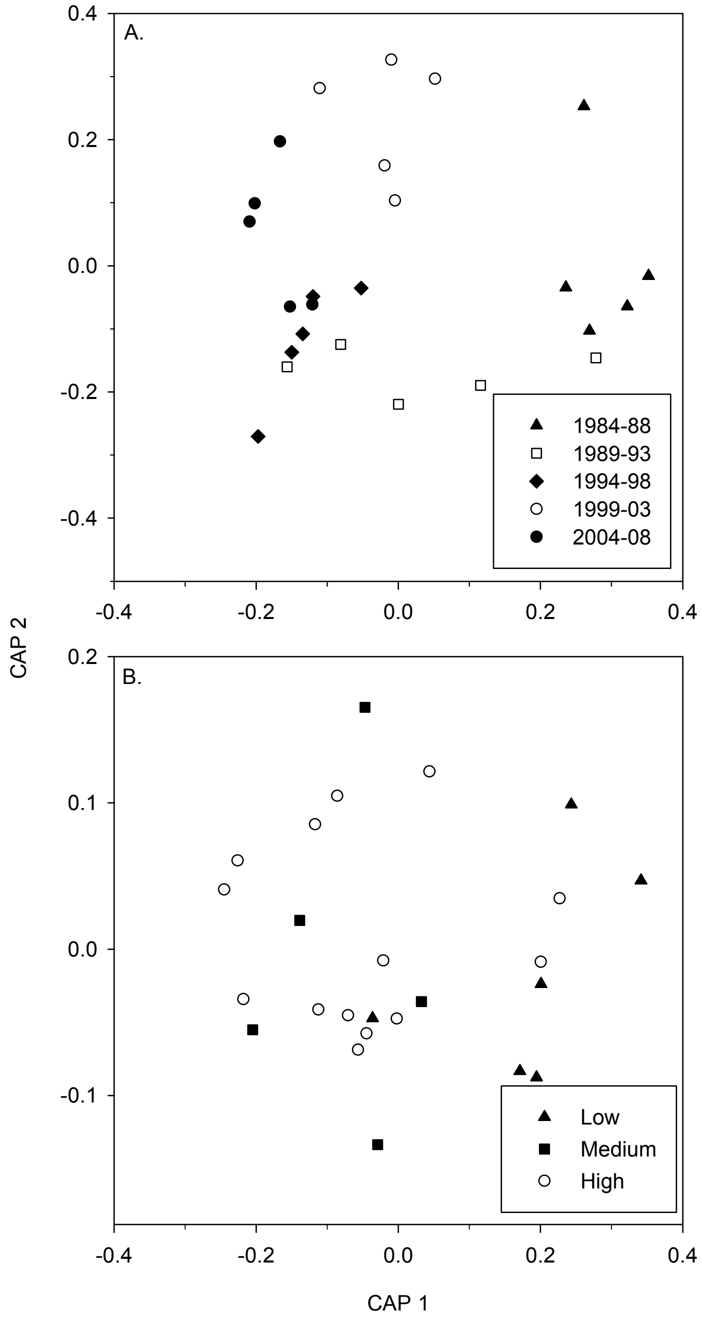

Figure 3-2. Canonical analysis of principal coordinates of annual catches from the Lakes and Coorong Fishery between 1984 and 2008; (A) for five 5-year periods, and (B) for low (< 3,000 $GL.y^{-1}$) , medium (3,000 to 6000 $GL.y^{-1}$), and high (> 6,000 $GL.y^{-1}$) annual freshwater inflows.

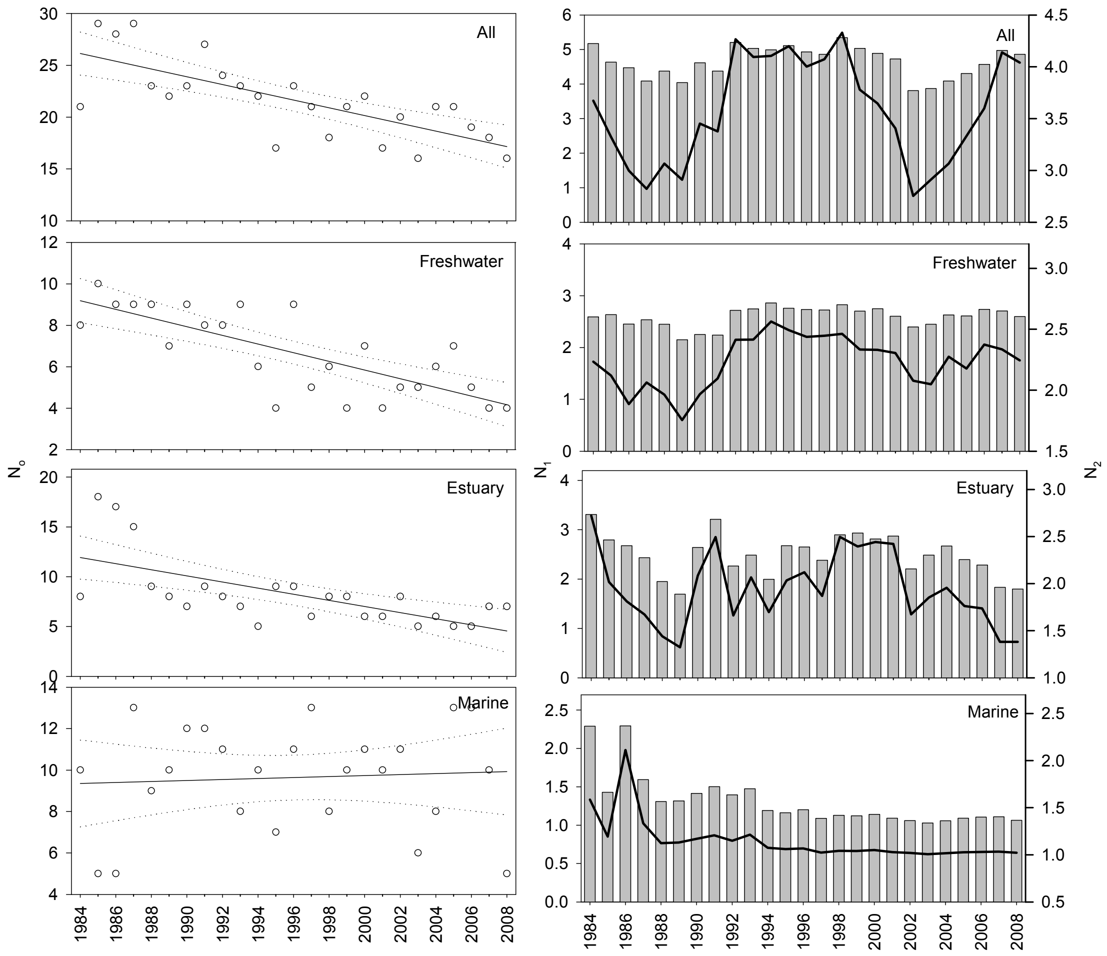

Figure 3-3. Hill's numbers for species richness (H_0, open circles), diversity (N_1, bars) and evenness (N_2, line) estimated from historical catch data from three habitats in the lower Murray River system. Species richness: solid line is linear regression and dotted lines are 95% confidence intervals.

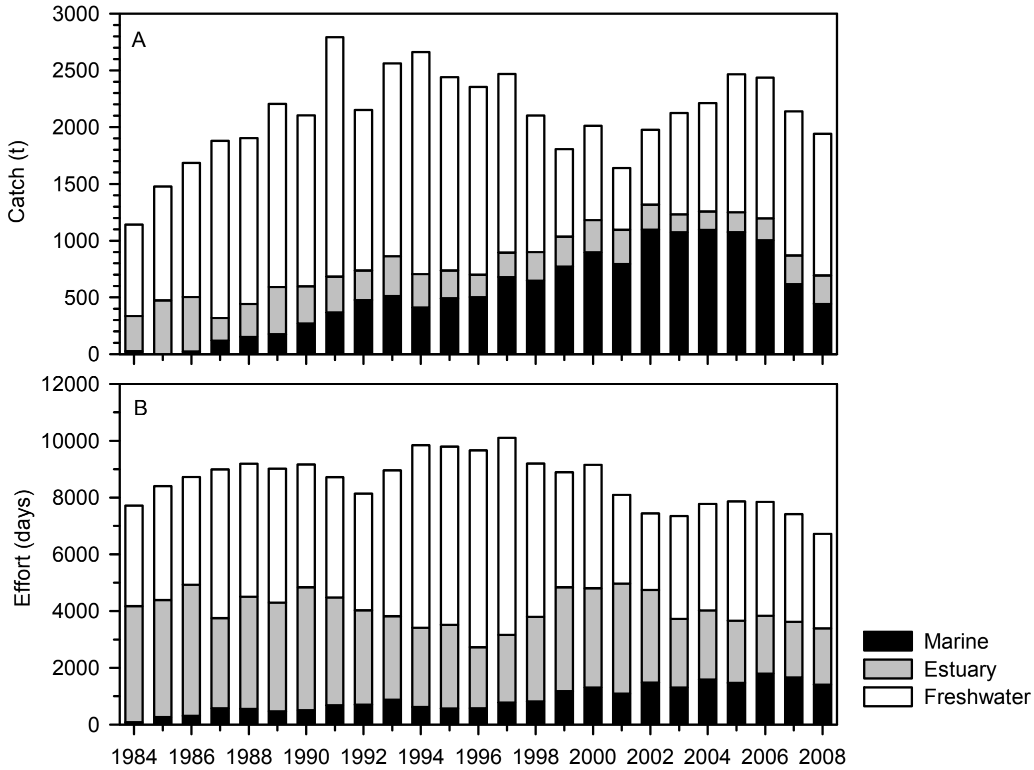

Figure 3-4. Catch (A) and effort (B) associated with commercial fishing in marine, estuarine and freshwater habitats in the lower Murray River system.

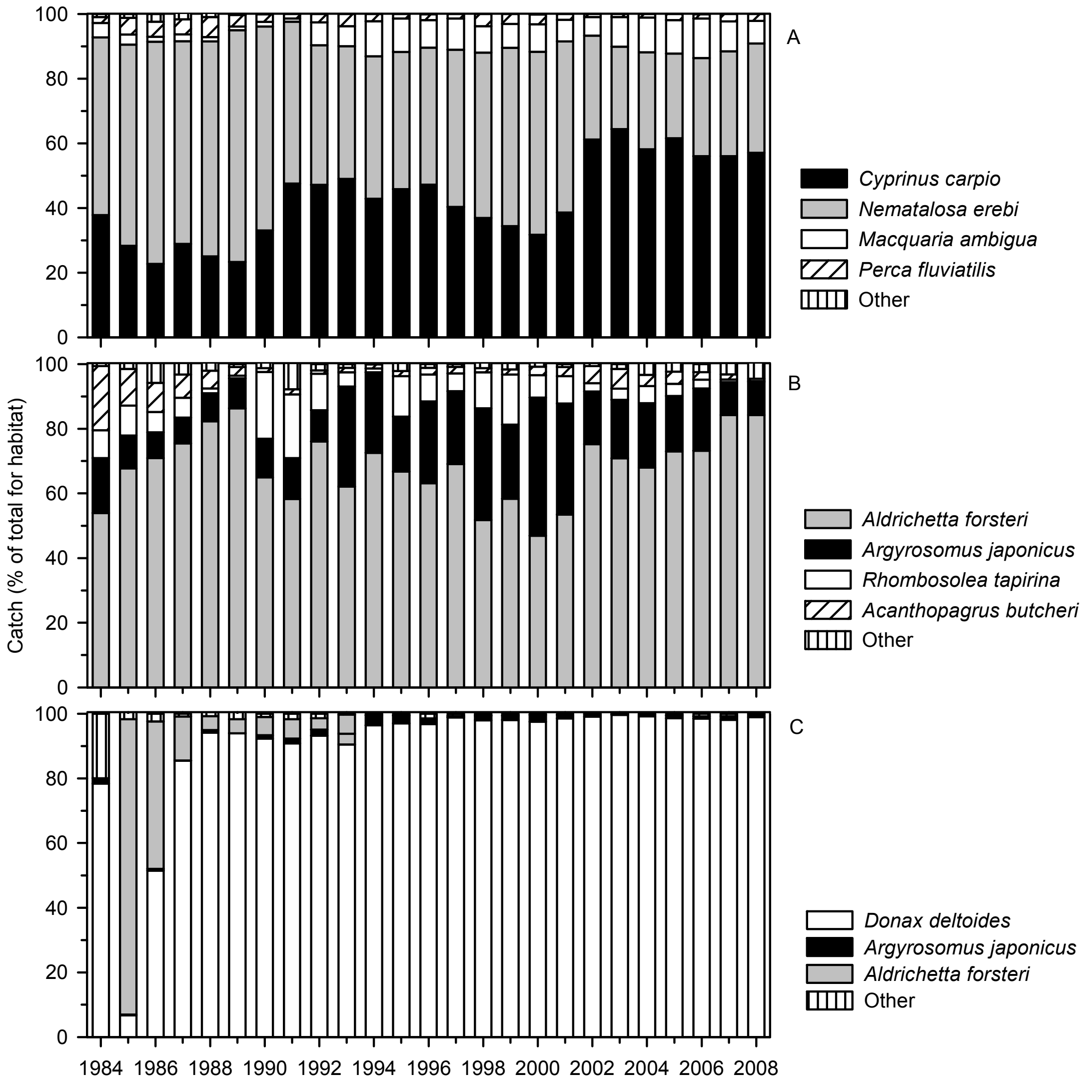

Figure 3-5. Catch species composition from (A) freshwater, (B) estuarine, and (C) marine habitat in the Murray River system.

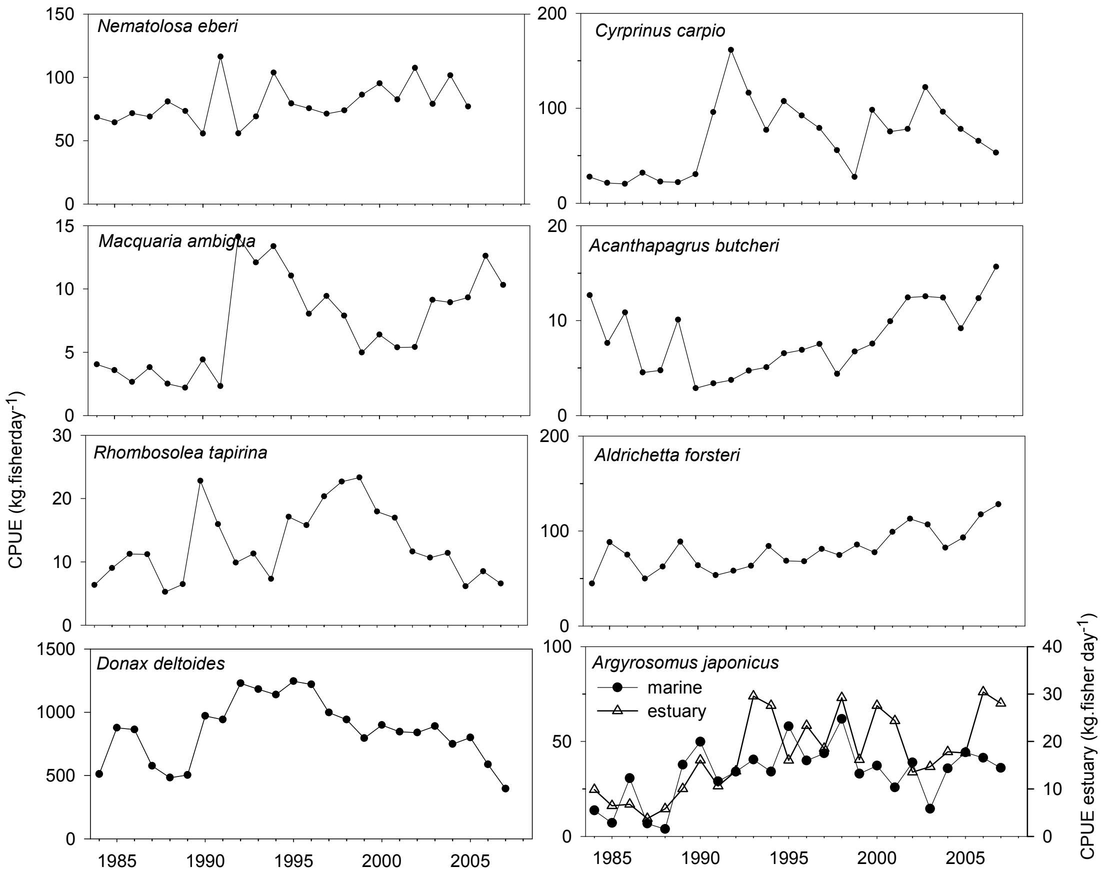

Figure 3-6. Relative abundance of exploited species in lower Murray River system: *Nematalosa erebi*, *Cyprinus carpio* and *Macquaria ambigua* in freshwater habitat; *Acanthopagrus butcheri*, *Rhombosolea tapirina*, *Aldrichetta forsteri*, and juvenile *Argyrosomus japonicus* in estuarine habitat; and *Donax deltoides* and adult *A. japonicus* in adjacent marine habitat.

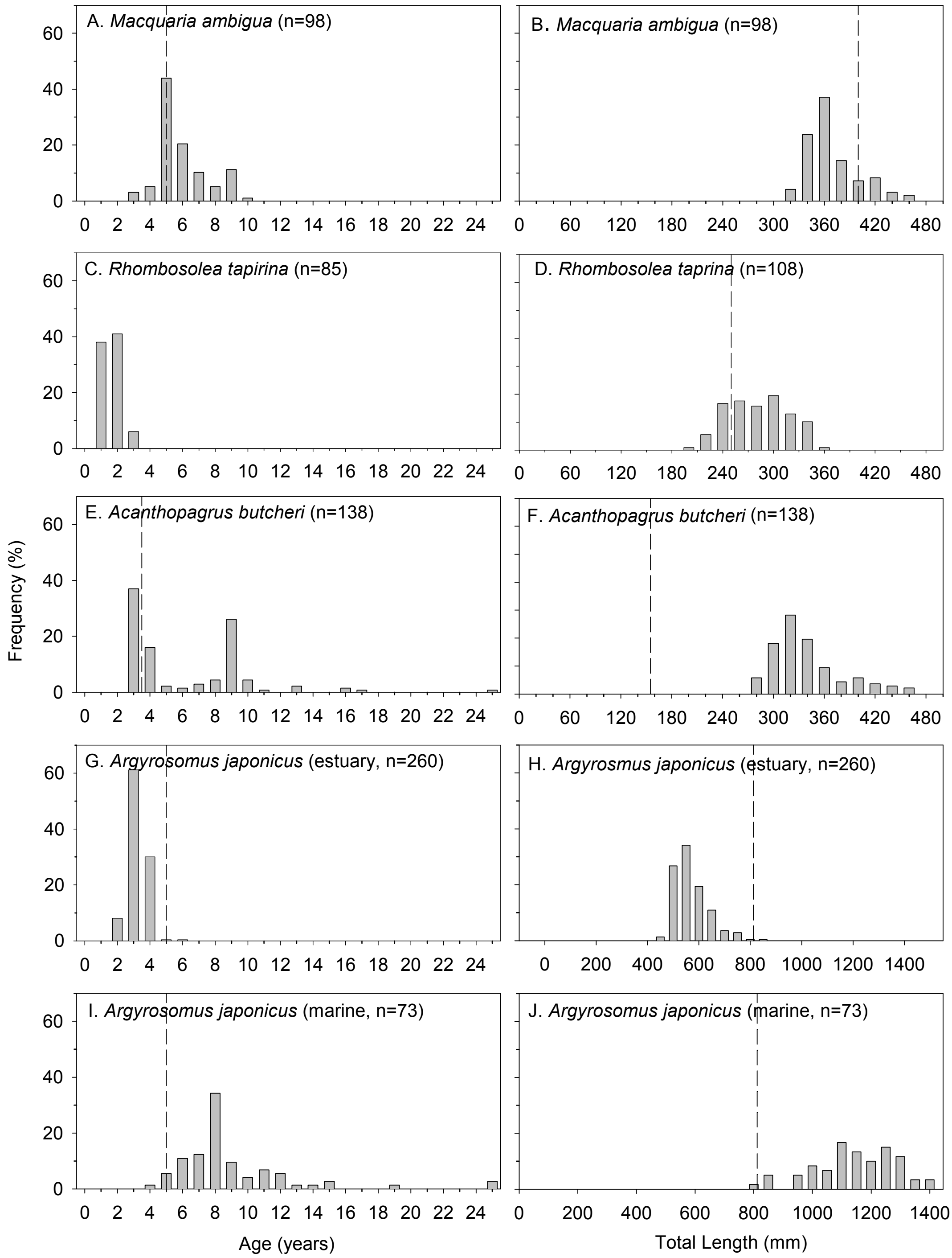

Figure 3-7. Age (left) and size structures (right) for commercial catches from freshwater (A, B); estuarine (C - H), and nearshore marine (I, J) habitats. Vertical dashed line represents age/size of maturity.

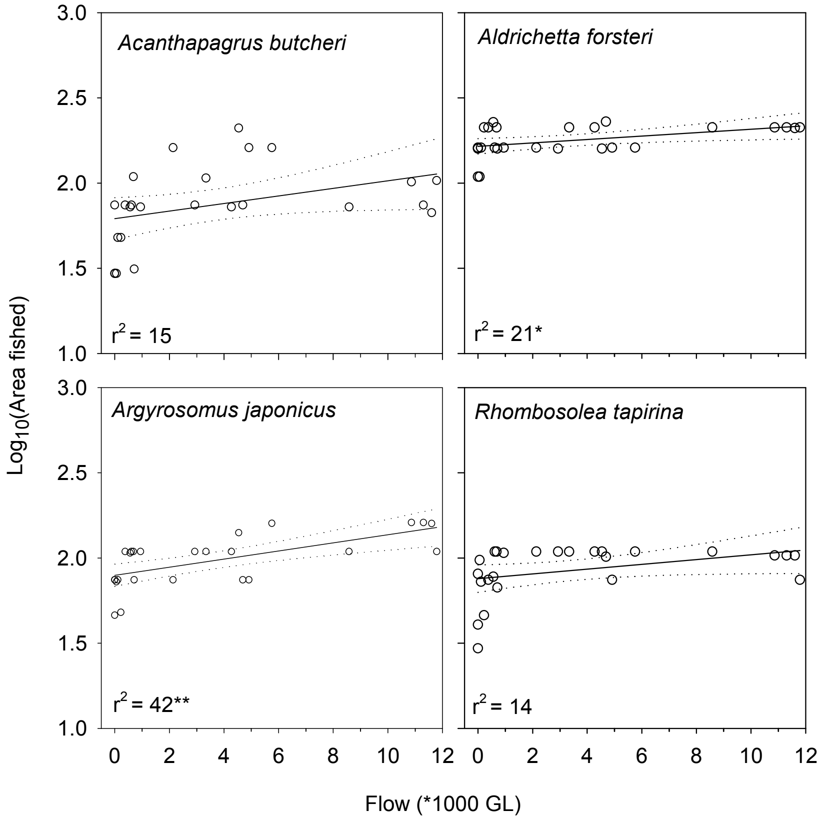

Figure 3-8. Relationships between annual freshwater flows and area of Murray River estuary that was fished in that year. Significant correlations are marked * (p <0.05), or ** (p<0.005).

4 DISCUSSION

Changes in the species composition of catches in the LCF suggest that the structure of the fish assemblage in the lower River Murray system has changed in the 25 years from 1984 to 2008. In freshwater and estuarine habitats, species richness declined and the abundances of species with opportunistic life history strategies and generalist habitat requirements increased. The truncation of the age structures of four species of long-lived, large-bodied, native fishes suggests environmentally-induced recruitment failure, longevity over-fishing and compromised egg production. These periodic strategists require strong freshwater flows for successful reproduction and it is important that the remnant populations be protected from over-exploitation until environmental conditions conducive to successful reproduction are restored to the system.

Temporal changes in the species composition of catches in the LCF were due to impacts of reduced freshwater flows, fishing pressure, or a combination of both factors. However, separating the effects of such factors in freshwater and estuarine environments is difficult (Laë 1995; Cabral et al. 2001), particularly when major changes to population and assemblage structure, and collapse of populations occur prior to data collection (Dayton et al. 1995; Jennings and Kaiser 1998). This may be the situation in the lower Murray River system where fish populations have been exploited for more than 100 years and freshwater flows have been restricted for almost 70 years. For example, prior to construction of the barrages in the early 1940's, catches of mulloway were an order of magnitude larger than those of the last 25 years (Ferguson et al 2008). Similarly, records from fish processors indicate a steep decline in the catches of Murray cod from 140 to 2 $t.y^{-1}$ between 1954 and 1975, almost a decade before collection of fishery catch and effort information (Ye et al. 2000, Table 1).

The similarity in species composition of catches from the LCF in the five-year periods of 1989-93 and 1994-98, and high diversity of abundant species (Hills N_2), reflects the successful recruitment of flood-dependent species during 1989-93 when floods (>10,000 $GL.y^{-1}$) occurred in four of five years and the persistence of strong age classes through 1994-98 (Figure 3-2A). The potential for multiple flood years to have cumulative, persistent effects on the structure of fish assemblages has been identified for freshwater species (Puckridge et al. 2000; Leigh et al. 2010). It is notable that the 1993 age class still dominated the mulloway population in 2002 (Figure 3-8).

Since 1993 the frequency of strong flows into the lower Murray River system has diminished and there have been no years when flows have exceeded 10,000 $GL.y^{-1}$ (our definition of a flood). This reduction explains the difference between the species composition of catches in 1989-93 and 1994-98 and subsequent 5-year periods (Figure 3-2B), when declines in both species richness and diversity of abundant species occurred in freshwater and estuarine habitats. Reductions in flow may have reduced the abundance of species, such as golden perch, black bream and mulloway which are dependent on strong flows for successful recruitment. The change in species composition of catches over time may also reflect the reductions in abundance of exploited species due to fishing (Blaber et al. 2000), particularly for periodic strategists, such as golden perch, black bream and mulloway.

In freshwater habitat, catches prior to this study were dominated by the periodic strategist Murray cod (Rowland 1989; Ye et al. 2000). However, during the present study, the periodic strategist species, including golden perch, contributed less than 10% of the total annual catch whilst opportunistic species dominated (>90%). Prior to the current drought, catches were dominated by bony bream, which is the only large-bodied, native species that has not declined significantly since river regulation in the 1940's. The successful recruitment of this species is not dependent on river flows (Puckridge and Walker 1990). Since the current drought there have been significant increases in catches of the exotic European carp. Although this species has been established in the lower River Murray for decades, and is now the most abundant, large-bodied fish species in the region (Gehrke et al. 1995; Smith 2005), its recent success may be because carp are generalists that can perform well in anthropogenically degraded habitats (Cadwallader 1978; Koehn 2004). Furthermore, successful recruitment is not dependent on strong flows (Ye et al. 2008). The recent, low abundance of golden perch may be due to its dependence on elevated water temperatures and flooding for successful recruitment (Mallen-Cooper and Stuart 2003; Ye 2004; Ye et al. 2008). The truncated age structures of this species, with the oldest individuals only 62% of the maximum age, reflect the effects of fishing which removes older, larger individuals from populations (Hilborn and Walters 1992; Planque et al. 2010; Walsh et al. 2010).

In the estuarine habitat, the combined catches of the periodic strategists, mulloway and black bream and the intermediate strategist greenback flounder decreased from ~52% in 2000 to ~12% in 2008. During this period, catches were increasingly dominated by the opportunistic strategist yellow-eye mullet. The apparent increase in the relative abundance of yellow-eye mullet may be due to its: (i) tolerance of a wide range of salinities (Young and Potter 2002); (ii) ability to recruit successfully each year regardless of freshwater inflows; and (iii) reduced predation by mulloway. Although the population of yellow-eye mullet in the estuary is thought to be self-recruiting, it is a marine species that uses estuarine habitat opportunistically (Harris 1968; Lenanton and Potter 1987), and there is potential for recruitment from the marine environment.

Environmental limitation of populations of periodic strategists in the estuarine habitat, i.e. mulloway, and black bream, partly explain their declining abundance. Lack of strong freshwater inflows since 1993 may have resulted in poor recruitment of mulloway, with possible recruitment failure in recent drought years (Hall 1986; Griffiths 1996; Ferguson et al. 2008). Black bream may also depend on freshwater inflows and other environmental cues for successful spawning and recruitment (Hobday and Moran 1983; Norriss et al. 2002; Nicholson et al. 2008). The truncated age structures of both species with the oldest individuals captured being significantly younger than the recorded maximum ages suggest that fishing has also impacted these populations (Hilborn and Walters 1992; Planque et al. 2010; Walsh et al. 2010). Age structures of greenback flounder in the estuary appears to be particularly truncated as only one and two year old females comprised >95% of the population, while longevity is >6 years (Stevens et al. 2005).

Species composition of catches in the marine habitat has not declined over time and after 1998, >90% was contributed by the r-strategist pipi. Although the relative abundance of pipi appeared to be positively related to freshwater flows (Table 3-2), this finding should be interpreted with caution because of the long-term decline in relative abundance, combined with high effort and catch, (Ferguson and Mayfield 2006) which suggest that severe overfishing occurred contemporaneously with the recent drought (Figures 3-5, 3-6).

Information available for assessment of fish in ecosystems commonly includes fishery catches, estimates of relative abundance from CPUE, and species composition. Total catch (biomass) provides a poor indicator of the performance of a multi-species fishery because it may fail to capture temporal or spatial changes in catch composition. In this study, total annual effort and catches were relatively consistent, but the proportional contribution from each of three fished habitats, and the species within them, varied among years. An overall decline in catches of finfish was compensated for by relocation of effort to a population of bivalve in marine habitat. This is consistent with other studies of multi-species fisheries that have reported stable total annual catches whilst catch species composition changed (May et al. 1979; Laë 1995). For example, in the North Sea, the catch of herring and mackerel declined over 10 years, but total catches remained constant due to increasing catches of gadoids such as Norway pout (May et al. 1979).

At the population level, CPUE often provides the only available estimate of relative abundance, although its use over extended periods may be problematic. CPUE may not be proportional to abundance over the entire exploitation history of a given population (Maunder 1998) and requires interpretation in the context of each species' life history and likely response to environmental factors such as drought (King and McFarlane 2003). CPUE may also provide an inconsistent index of relative abundance in highly changeable environments such as in end-river systems. For example, CPUE may over-estimate relative abundance of mulloway and black bream because the area of estuarine habitat that is available, contracts as freshwater inflow decreases. Other studies have suggested that changes in freshwater inflows affect catchability of estuarine fish because of effects on migration and schooling caused by associated salinity fluctuations which may alter habitat availability (Loneragan and Bunn 1999; Gillson et al. 2009). CPUE may also overestimate relative abundance when fish are targeted as they aggregate to spawn, which may be the case for black bream and greenback flounder in the estuary and mulloway in the marine habitat.

Species composition of catches may provide a useful indicator of spatial and temporal changes in fish assemblages. In this study, we found that fish assemblages changed over time, and that flood, drought and fishing were likely causal factors. Of most concern was: (i) the temporal trend of increasing contribution to catches from shorter-lived, early-maturing, habitat generalists that have the ability to recruit successfully each year, and (ii) reduced contributions of long-lived, late maturing, environmentally-limited species.

Results from this study suggest that a suite of indicators may provide the most robust estimation of the relative impacts of anthropogenic environmental effects and fishing on ecosystems. Together, time series of biomass (total catches), catch composition and species diversity indices provide a broad indicator of ecosystem health (Whitfield 1996; Soto-Galera et al. 1998). However, understanding the relative impacts of environmental change and fishing and the potential for rebuilding of populations requires supplementary information, including detailed life-history information and time-series of age structure data.

Management of multi-species fisheries needs to be tailored to the most sensitive species, rather than the most robust (Myers and Worm 2005). Consideration of life-history strategies is fundamental to assessments of resource status (King and McFarlane 2003) and should recognise the vulnerability of periodic strategist to longevity over-fishing: especially when successful recruitment is infrequent (Beamish et al. 2006). In the Murray River system, populations of golden perch, mulloway and black bream rely on the establishment of one, or two, strong year classes at irregular intervals to maintain their populations. The truncated age distributions of these species provide evidence that they are longevity overfished (Beamish et al. 2006). Continued over-exploitation will reduce their potential egg production and capacity to produce strong age classes when environmental conditions again become favourable (Myers and Worm 2005; Hsieh et al. 2006; Hsieh et al. 2010). The first step to rebuilding the populations of large-bodied, native species in the Murray River system is to protect existing populations from further over-exploitation.

Management options for preventing further over-exploitation are to: (i) increase size limits to protect immature fish; (ii) reduce by-catch of juveniles of target species; (iii) establish an upper size limit to protect large, highly fecund females; (iv) protect spawning aggregations from fishing, and (v) restrict gear-types used to target periodic strategists. For periodic strategists, setting an LML that protects immature and young adult fish is critically important. While the size at which 50% of females mature (SOM_{50}) is commonly used for opportunistic species, more conservative LMLs may be needed for periodic strategists, especially in habitats where conditions favouring successful recruitment are infrequent. It is notable that the LML for black bream (280 mm TL) is 80% higher than the SOM_{50} (Norriss et al. 2002) and although this species' age structure is truncated, it is the only large-bodied, native fish with more than one strong year class in the population. In contrast, the LML of 460 mm TL for mulloway in the estuary is 44% below SOM_{50} (Ferguson, in prep) and approximately 90% of the commercial catch is comprised of sexually immature individuals (Ferguson and Ward 2003). Allowing recruits to become established in the adult population is essential if age structures are to rebuild. However, the bycatch of estuarine fisheries typically includes juveniles of the target species (Gray 2002; Gray et al. 2004). Many recruits do not reach LML when by-catch mortality is high. A recent study showed that the number of sub-legal sized mulloway taken incidentally in gillnets in the Murray River estuary is equivalent to the number harvested, and rates of survival are low (23% alive at capture) (Ferguson 2010).

The results of this study have implications for the management of fish populations in a changing climate. The decline in species richness over 25 years in both freshwater and estuarine habitats and decline in diversity of abundant species since 2002 in estuarine habitat may contribute to reductions of ecosystem resilience and increase sensitivity to climate change (Worm et al. 2006). In addition, under predicted climate change scenarios, populations of long-lived species with fisheries-induced, truncated age structures, may be more prone to collapse (Planque et al. 2010). This is particularly important for environmentally-limited populations of golden perch, mulloway, black bream and greenback flounder due to current impacts of drought on critical habitat and climate change predictions that indicate further reduction to freshwater inflows of 15% by 2030 and up to 35% by the 2050's (Hughes 2003).

Conclusions

Species composition of catches provides valuable information about fish assemblages and populations. In combination with information on demography and species' life-histories catch composition information may provide: (i) indications of changes in environmental health, (ii) identify vulnerable populations, and (iii) inform management of multi-species fisheries in highly changeable environments such as estuaries.

Management of periodic strategist species, in end-river and estuarine habitats should seek to preserve age structures, because populations of these species depend on healthy age-size structures to withstand environmental variability. Management of the commercially-exploited, large-bodied, native species golden perch, mulloway, black bream and greenback flounder in the drought-affected, lower Murray River system should seek not only to preserve remnant age structures, but also to rebuild them.

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