Aquat. Living Resour. 21, 145–152 (2008)

DOI: 10.1051/alr:2008034
www.alr-journal.org

Aquatic Living Resources

Do recent age structures and historical catches of mulloway, *Argyrosomus japonicus* (Sciaenidae), reflect freshwater inflows in the remnant estuary of the Murray River, South Australia?

Greg J. Ferguson[1,a], Tim M. Ward[1] and Michael C. Geddes[2]

[1] SARDI Aquatic Sciences, PO Box 120, Henley Beach, South Australia 5024, Australia
[2] School of Earth & Environmental Sciences, University of Adelaide, Adelaide, South Australia 5005, Australia

Received 3 July 2007; Accepted 4 April 2008

Abstract – Patterns of annual freshwater flows in the Murray River and recruitment of mulloway, *Argyrosomus japonicus* (Scianidae) were reviewed in terms of recent age structures and historical catches and CPUE. Age distributions from the nearshore marine fishery were dominated by the 1993 age class which comprised 35% and 41% of 2001 and 2002 catches, respectively. In 1993 annual freshwater inflow was 2.4 times the 25 year average. Freshwater inflow explained 28% and 35% of the variability in year class strength in the nearshore marine fishery in 2001 and 2002, respectively. Over 80% of the current South Australian commercial catch of mulloway comprises juveniles taken from the remnant estuary of the Murray River. Our results suggest that recent low levels of recruitment in South Australia's fisheries for *A. japonicus* may reflect low fresh water inflows since 1993. Since 2000, southern Australia has experienced the worst drought in recorded history and management strategies for this fishery must take into account effects of both environmental factors and fishing mortality on this vulnerable sciaenid population. We suggest that the population of *A. japonicus* located about the Murray River system is estuarine dependent, that the estuary provides important refuge for juveniles, and that strong year classes, or their absence, may be related to freshwater inflow to this environment. We also suggest that age distributions of this apex predator may provide an indicator of environmental health for the Murray River estuary.

Key words: Estuaries / River flows / Fisheries / Recruitment / Nursery grounds / Sciaenidae / *Argyrosomus* / Australia

Résumé – Les récentes structures en âge et les captures historiques de *Argyrosomus japonicus* (Sciaenidae) reflètent-elles les apports en eau douce dans l'estuaire résiduel du fleuve Murray, Australie-Méridionale ? Le modèle annuel des apports d'eau douce du fleuve Murray et le recrutement de *Argyrosomus japonicus* (Sciaenidae) sont étudiés en termes de récentes structures en âge, de captures historiques et de prises par unité d'effort (CPUE). La distribution en âge des captures, de la pêcherie côtière maritime, est dominée par la classe d'âge 1993, qui représente respectivement, 35 % et 41 % des captures 2001 et 2002. En 1993, l'apport annuel d'eau douce a été 2,4 fois celui de la moyenne de 25 années. L'apport d'eau douce explique 28 % et 35 % de la variabilité de la force d'une classe d'âge de la pêcherie côtière en 2001 et 2002, respectivement. Plus de 80 % des captures commerciales habituelles de l'Australie-Méridionale consiste en juvéniles, pris dans l'estuaire résiduel du Murray. Nos résultats suggèrent que les récents faibles niveaux de recrutement de *A. japonicus* dans les pêches de l'Australie-Méridionale pourraient refléter les faibles apports d'eau douce depuis 1993. Depuis 2000, l'Australie-Méridionale a expérimenté la pire des sécheresses de son histoire, et des stratégies de gestion de cette pêcherie doit tenir compte des effets environnementaux et de la mortalité par pêche de cette population vulnérable de Scianidés. Nous pensons que cette population de *A. japonicus* située aux environs du fleuve Murray est dépendante du système estuarien, que l'estuaire fournit un important refuge pour les juvéniles, et que de fortes classes d'âge, ou leur absence, pourraient être liées aux apports en eau douce à cet environnement. Nous suggérons également que les distributions en âge de ce grand prédateur pourrait fournir un indicateur de santé environnementale de l'estuaire du fleuve Murray.

[a] Corresponding author: ferguson.greg@saugov.sa.gov.au

Article published by EDP Sciences

1 Introduction

Estuarine habitats are critically important for many species, including waterbirds, fishes and invertebrates (Blaber 1980; Lenanton 1982; Beck et al. 2001). The abundance of several estuarine-associated finfish species has been shown to be associated with environmental flows of freshwater (see review in Gillanders and Kingsford 2002) with a number of examples from tropical Australian estuaries (Loneragan and Bunn 1999; Robbins et al. 2005; Meynecke et al. 2006).

The Murray-Darling is Australia's largest river system and, in terms of catchment area and length, ranks approximately twentieth amongst the worlds great rivers (Newman 2000). The original Murray River estuary covered 660 km^2, and included the brackish Lakes Alexandrina and Albert, and the north and south Coorong lagoons (Fig. 1). In 1940, a series of barrages were constructed between the Lakes and lagoons, reducing the estuary to 11% of its original size. Since then, water abstraction for irrigation has reduced mean annual flow to 20% of natural levels (Thomas 1999). The extent and frequency of the natural spring floods has been reduced, and in some years they do not occur at all. 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). From 2001 to 2008 the Murray River system has experienced the worst drought in recorded history.

The remnant estuary of the Murray River is recognised internationally as an important breeding and feeding ground for waterbirds, and supports significant populations of several species of fish and invertebrates. The Murray River ecosystem is the largest estuarine habitat in temperate Australia and is the geographical centre of the Australian distribution of mulloway, *Argyrosomus japonicus* (Perciformes: Sciaenidae), a species known to be associated with estuaries in Australia (Hall 1986; Lenanton and Potter 1987; Gray and McDonall 1993) and South Africa (Griffiths 1996).

Australia's largest commercial fishery for *A. japonicus* operates in the Murray River estuary and nearby marine environments (Ferguson and Ward 2003, Fig. 1) and has two multispecies sectors: the Lakes and Coorong Fishery (LCF) and the Marine Scale Fishery (MSF). The LCF operates within, and adjacent to the Murray River estuary, while the MSF operates in nearshore marine waters along the entire South Australian coastline. Fishers in the LCF harvest >90% of the South Australian commercial catch of *A. japonicus* by using gill nets in two broad habitats: the estuarine environment of the Murray River and the nearshore marine environment near the rivermouth. The minimum legal harvest size of *A. japonicus* within the Murray River estuary is 46 cm TL but is 75 cm TL in all other waters in South Australia. The catch from the estuarine fishery is comprised almost exclusively of juveniles whilst the catch from the nearshore marine fishery comprises reproductively mature and sub-mature adults that aggregate at the interface of the Murray River plume during the spring-summer (November to March) spawning period (Ferguson and Ward 2003). Overall, approximately >80% of the South Australian commercial catch of *A. japonicus* are juveniles (<75 cm TL) harvested from the Murray River estuary (Ferguson and Ward 2003).

This area is also fished by recreational line fishers who regard *A. japonicus* as an "icon" species. In 2000, recreational fishers harvested 38% of the combined commercial and recreational catch for South Australia (Henry and Lyle 2003). Like the commercial fishery, most of the catch is taken near the mouth of the Murray River, but in contrast to the commercial fishery most of the fish are adults from the prespawning/spawning aggregation in nearshore marine waters (Jones and Doonan 2005).

In southern Australia, fishers and others (Hall 1984; Anon. 1985; Hall 1986) have attributed variability in the annual catch of *A. japonicus* from the Murray River estuary, to variability in freshwater inflows. This study aims to examine relationships between: (i) relative age class strength of *A. japonicus* and freshwater inflow, (ii) historical catch and effort data from the fisheries for *A. japonicus* and freshwater inflow (iii), and the spatial distribution of *A. japonicus* within the Murray River estuary.

2 Materials and methods

2.1 Freshwater inflow and fishery data

In this paper, "inflow" refers to freshwater from the Murray River entering the estuary through the barrage system. Estimated mean monthly freshwater inflow to the Murray River estuary were obtained from the regression based Murray hydrological model (MSM BIGMOD, Murray-Darling Basin Commission) for financial years beginning 1962 to 2005. Mean monthly inflow, in megalitres, were converted to SI units (m^3 s^{-1}). Highest monthly flows occurred during late spring (August-November) and summer (December-February) and were aggregated into financial years to align with the seasonality of catch and effort in the fishery. All freshwater inflow, age and catch data are reported in financial years i.e. 1962 represents the period from July 1, 1962 to June 30, 1963. Mean annual catch per unit effort (CPUE) was estimated for the estuarine and nearshore marine fisheries by dividing the annual catch by the annual effort in terms of fisher days. Data available for linear regression analyses are shown in Table 1.

2.2 Age distributions

The LCF uses different types of gill nets to target *A. japonicus* in the estuary and the nearshore-marine environments. In the estuary, gill nets (>115 mm mesh) were set at dusk at 90 degrees to the edge of the main channels and retrieved at dawn. In the nearshore marine fishery, gill nets (245 mm mesh) were operated as "swinger nets". One end of the net was anchored to a motor vehicle (typically a 5 tonne truck) located on the beach. The free end of the net was then drifted 500–700 m out to sea and then drifted through the surf zone with the longshore current (for up to 5 km), while the anchoring vehicle moved along the beach. Recreational fishers targeted *A. japonicus* in the nearshore marine environment with rod and line.

Sagittal otoliths were sampled from commercial catches from the Murray River estuary and the nearshore marine environment adjacent to the River mouth in 2001 and 2002. This

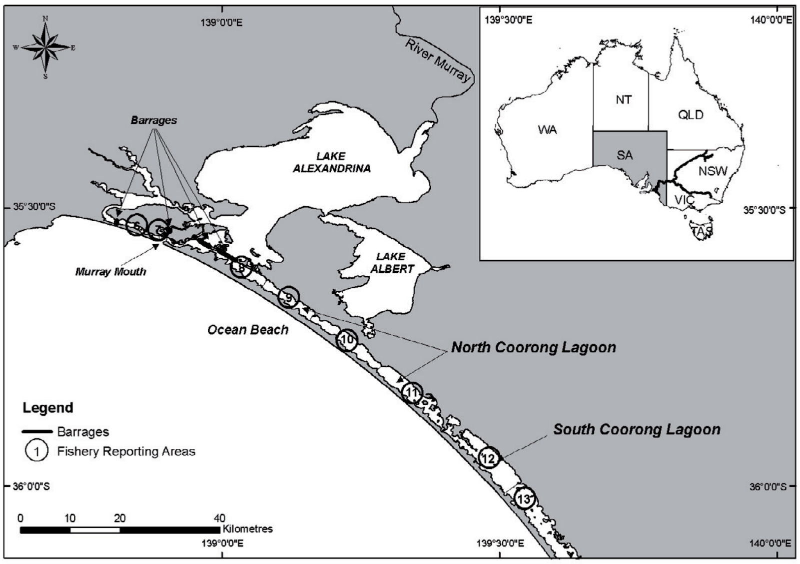

Fig. 1. Map of Australia showing South Australia (SA) and the Murray River (inset) and the remnant estuary of the Murray River comprising the Coorong lagoons. Also shown are Lakes Alexandrina and Albert which were part of the original estuary. Circled numbers are fishery reporting areas.

was done at either the point of landing or at the Adelaide Central Fish Market. In 2001 otoliths were also sampled from recreational catches taken in nearshore marine environment. 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. The left sagitta from each pair was embedded in fibreglass resin, and a longitudinal section cut with a diamond blade mounted on a Gemmasta 6" (150 mm) bench top saw. The 500 μm thick section was cut so as to incorporate the otolith centre and the sections were mounted on glass microscope slides using Cyano-Acrylate glue. The mounts were examined using a Leica MZ-16 dissector microscope with incidental light and ages estimated from counts of opaque zones. Annual deposition of opaque rings has been validated for *A. japonicus* in South Africa and Western Australia (Griffiths and Hecht 1995; Farmer 2003). The pattern of deposition for otoliths from South Australia suggests that the opaque zone is deposited in November-December (Ferguson, in prep.).

All statistics were performed using SPSS 14.0® and all data tested for departure from normality prior to performing analyses where a normal distribution was assumed. Age distributions were compared using the Kolmogorov-Smirnov 2-sample goodness of fit test. Relative year class strength (percentage of total sample for year) from age distributions from the nearshore marine environment in 2000 and 2002 were related to freshwater inflow using linear regression.

2.3 Commercial catches and CPUE

Freshwater inflow to the Murray River estuary (independent variable) was compared with CPUE (kg fisher^{-1} day^{-1}) from the commercial estuarine and nearshore marine fisheries from 1984 to 2005 (dependent variable) using linear regression (α = 0.05). Time lags were estimated from modes in the age structures for estuarine and nearshore-marine catches and validated by comparing them with cross correlations of CPUE and flow data over a range of time lags (Pearson correlation coefficient, CC). CPUE from the estuarine and nearshore marine fisheries were also compared.

2.4 Spatial distribution of commercial catches

Catches from the Murray River estuary were harvested from 10 fishery reporting areas. Each fishery reporting area represented a 10–15 km long section of the lagoons which comprise the estuary (Fig. 1). In years of higher freshwater inflow, a salinity gradient is established along a greater proportion of the lagoons (Geddes 1987), therefore, because juveniles are known to prefer lower salinities, they would be expected to occur along an increasingly greater proportion of the lagoons in years of higher inflow. Thus, in the absence of longitudinal salinity data for each year, the number of spatial reporting areas from which catch was reported was used as an index of the proportion of the estuarine habitat that was used by juveniles.

3 Results

3.1 Relationship between freshwater inflow to the Murray estuary and age distributions

Age distributions of *A. japonicus* from the commercial estuarine fishery (2001, n = 260; 2002, n = 91) had a modal

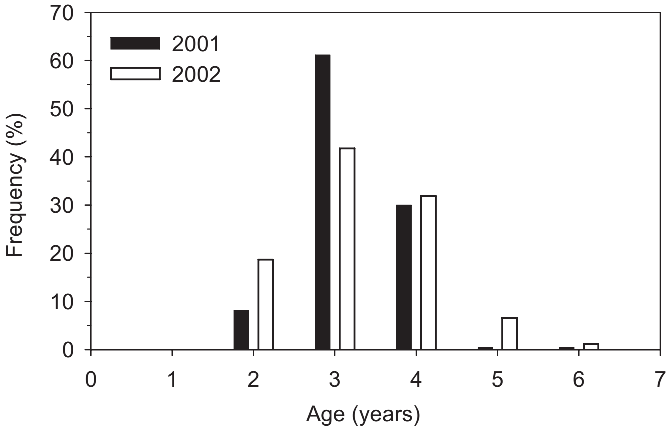

Fig. 2. Age structures of *Argyrosomus japonicus* from the Murray River estuary from 2001 and 2002 (n = 351).

age of 3 years and a range of 2 to 6 years (Fig. 2). Age distributions from recreational (n = 26) and commercial catches (n = 73) from the nearshore marine fishery in 2001 had a statistically identical distribution (K-S D = 0.555, p = 0.918) and were combined (n = 99). The combined samples were dominated by the 1993 year class (8 year olds, 35% of sample, Fig. 3A). Secondary modes occurred at year classes 1990 (11 years old, 8% of sample) and 1989 (12 years old, 4% of sample). The dominant 1993 year class persisted in commercial samples from 2002 (41% of sample, 9 years old, Fig. 3B). A smaller mode comprising the 1990 year class (8% of sample, 12 years old) was also present. The range of ages was 4 to 25 years in 2001 and 5 to 24 years in 2002 which represented year classes over 25 years from 1976 to 2001. The freshwater inflow in 1993 was 2.4 times greater than the 25 year average annual flow from 1976 to 2001 and in 1990 and 1989 was more than 2 times greater than the average for this period (Fig. 3C).

Freshwater inflow explained 28% of the variability in year class strength in combined samples from the nearshore environment in 2001 (linear regression, r^2 = 0.28, p = 0.006) and 35% in 2002 (linear regression, r^2 = 0.35, p = 0.001).

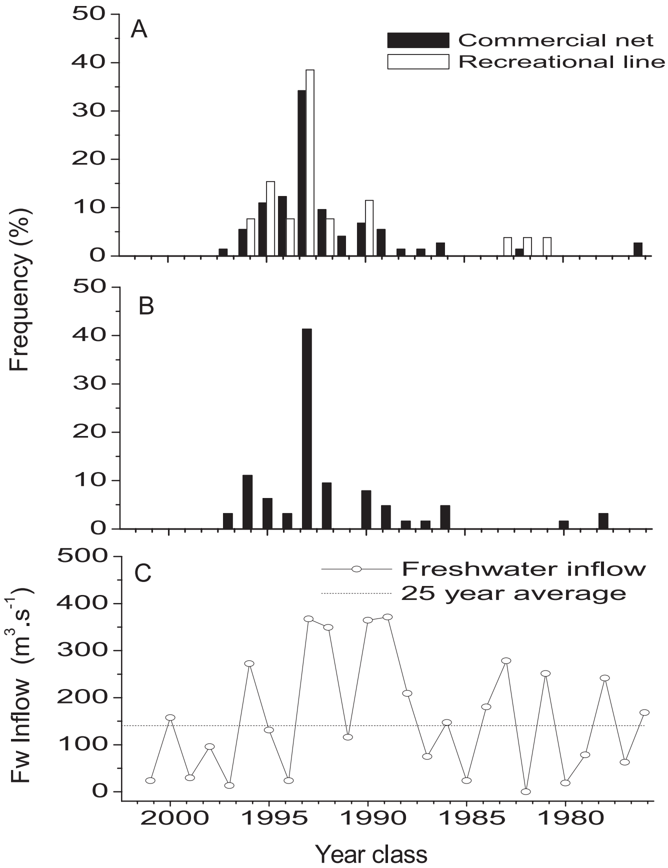

Fig. 3. Age distributions for commercial net (n = 73) and recreational line catch (n = 26) of *Argyrosomus japonicus* from the nearshore marine fishery in 2001 (A), commercial net catch from the nearshore marine fishery in 2002 (n = 63) (B), and freshwater inflow to the Murray River estuary (C). All x-axis scales are reversed to represent the year in which each year class was spawned.

3.2 Relationship between freshwater inflow to the Murray estuary and commercial catches and CPUE

South Australian total annual catches of *A. japonicus* from 1936 to 2005 are shown in relation to major hydrological events in Figure 4. The annual catch declined from a historic peak of 609 t in 1938 to 83% of this in 1941, coinciding with an 89% reduction in estuarine area associated with construction of the barrages in 1940. Catches continued to decline over the following 5 years, which included the 1943 drought, and in 1945 the catch was approximately 5% of the 1938 level. During the following 30 years three peaks in catches occurred (1957, 1966 and 1976), each preceded by a significant flood event (1955, 1963 and 1973 to 1974).

The Murray River mouth was closed due to drought in 1980 and catches remained below 100 t until 2001, when the catch was 145 t (Ferguson and Ward 2003). The mouth almost closed again in 1999 and drought conditions have prevailed since then. During this period the Murray River mouth has been kept open by a large-scale dredging program. Catches have continued to decline after 2001 and were 44 t in 2005 (Ferguson 2006).

In the nearshore marine fishery catches were strongly correlated with targeted effort, however there was a weak relationship between catch and targeted effort (fisher days) in the estuarine fishery (Table 1).

Freshwater inflows were generally a poor indicator of CPUE. For the period from 1984 to 2005, freshwater inflow (t-6 years, CC = 0.33) explained 16% of the variability in CPUE in the nearshore marine fishery (Table 1; Fig. 5A). There was no relationship between freshwater inflow and CPUE in the estuarine fishery from 1984 to 2005 (Table 1; Fig. 5B).

CPUE (t-3 years, CC = 0.72) from the estuarine fishery was positively related to CPUE from the nearshore marine fishery (Table 1; Fig. 6).

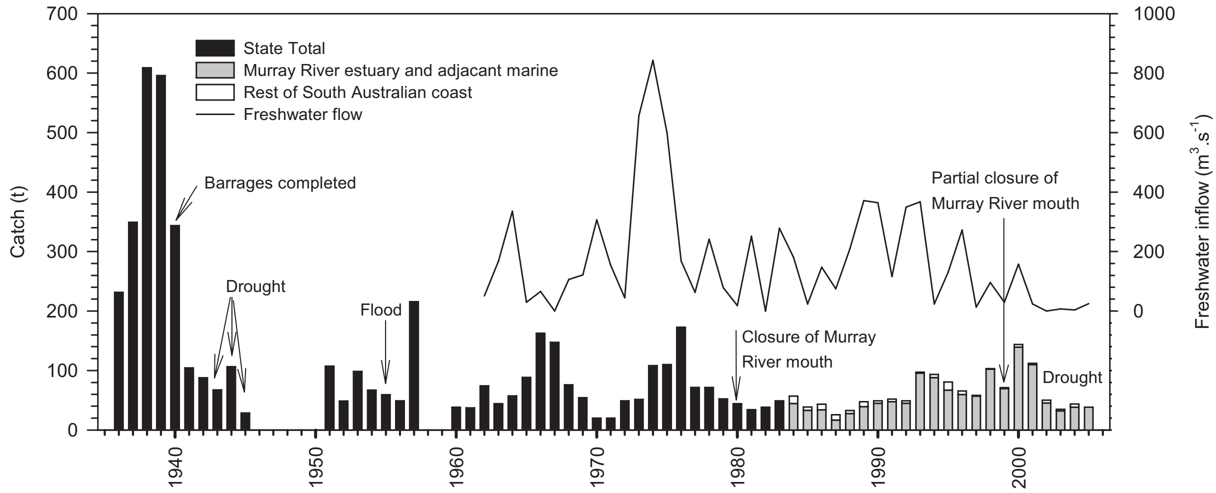

Fig. 4. South Australian total catches of Argyrosomus japonicus from 1936 to 2005 with key hydrological events annotated. From 1984 to 2005, catches are divided into those from the Murray River mouth/estuary and those from the rest of the State. Freshwater inflow to the Murray River estuary from 1961 to 2005 is also shown (time scale is in financial years (from July to June).

Table 1. Linear regressions performed on catch, effort and CPUE, showing years for which data were available for the Lakes and Coorong Fishery for *Argyrosomus japonicus* (estuarine = estuarine fishery, marine = nearshore marine fishery). The coefficients of determination (r^2) are shown with their p values (*significant, $\alpha = 0.05$).

Years when data available	Fishery	Independent variable	Dependent variable	Regression statistics	
				r^2	p
1984–2005	Estuarine	effort	catch	0.28	0.012*
1984–2005	Marine	effort	catch	0.90	0.000*
1987–2005	Estuarine, Marine	$\text{CPUE}_{(t-3\text{ years})}$ (estuarine)	CPUE (marine)	0.52	0.000*
1986–2005	Estuarine	fw. inflow	No. fishery reporting areas	0.43	0.002*
1984–2005	Estuarine	fw. $\text{inflow}_{(t-3\text{ years})}$	CPUE	0.00	0.832
1984–2005	Marine	fw. $\text{inflow}_{(t-6\text{ years})}$	CPUE	0.16	0.061

3.3 Relationship between freshwater inflow to the Murray estuary and spatial distribution of mulloway catches

Mean annual inflows explained 43% of the variability in the number of spatial reporting areas in the Murray River estuary where *A. japonicus* were harvested by the LCF (Table 1; Fig. 7).

4 Discussion

In this study, the modes in age distributions of *A. japonicus* from the nearshore marine environment suggested that a relationship may exist between freshwater inflow to protected nursery habitat in the Murray River estuary and subsequent recruitment to the fishery. The dominant year class from 1993 was present in samples from the nearshore marine environment in 2001 and persisted during 2002. This year class originated from the most recent year of relatively high freshwater inflow (>350 m^3 s^{-1}). Variability in annual freshwater inflows explained 28% and 35% of the variability in year class strength in 2001 and 2002 respectively.

The age distributions appear to be truncated with few individuals from year classes prior to 1991 even though 40 and 42 year old *A. japonicus* have been recorded in South Australia (Ferguson, unpublished data) and South Africa respectively (Griffiths and Hecht 1993). The absence of strong year classes prior to 1993 may have been caused by a combination of environmental impacts on recruitment and high levels of fishing mortality of both adults and juveniles (Ferguson and Ward 2003). The range of ages present was not related to gear selectivity because the age distributions from the nearshore marine net and line fisheries were statistically identical.

Truncation of the age distribution may reduce the capacity of the South Australian population of *A. japonicus* to withstand environmental events (Hseih et al. 2006). This hypothesis is supported by the high inter-annual variability in CPUE that characterises the fishery for *A. japonicus* (Ferguson and Ward 2003). Populations of long-lived species are typically buffered from recruitment-induced fluctuations in biomass by the presence of many age classes (McGlennon 2000; Scharf 2000). However, the survival of strong cohorts is critical for the maintenance of fish populations during periods of poor recruitment, when only weak year classes are produced. Fishing mortality of *A. japonicus* obviously reduces the survival of these strong cohorts.

Recruits of *A. japonicus* enter the estuarine fishery as 3 year old juveniles. They enter the nearshore marine fishery as sub-adults at 5–6 years old. CPUE in the estuarine fishery

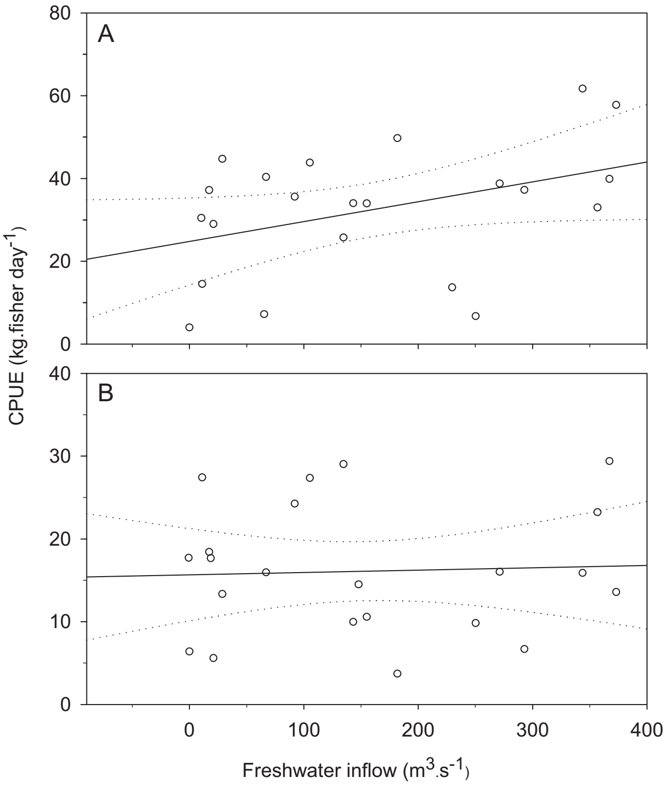

Fig. 5. Relationship between freshwater inflow to Murray River estuary and CPUE from (A) the estuarine and (B) the nearshore marine fisheries; 95% confidence intervals shown as dotted lines.

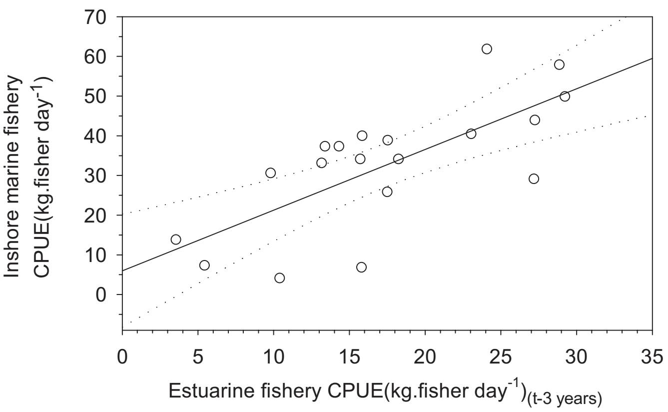

Fig. 6. Relationship between CPUE from the Murray River estuary and nearshore marine fisheries; 95% confidence intervals shown as dotted lines.

provided a good indicator of CPUE in the nearshore marine fishery 3 years later which suggests that individuals caught in the nearshore fishery originated from the Murray River estuary and that juvenile and adult *A. japonicus* from the Murray River system may comprise a discrete sub-population within South Australia.

CPUE in the nearshore fishery generally increased approximately 6 years after increases in annual freshwater inflows. No detectable relationship was found between freshwater

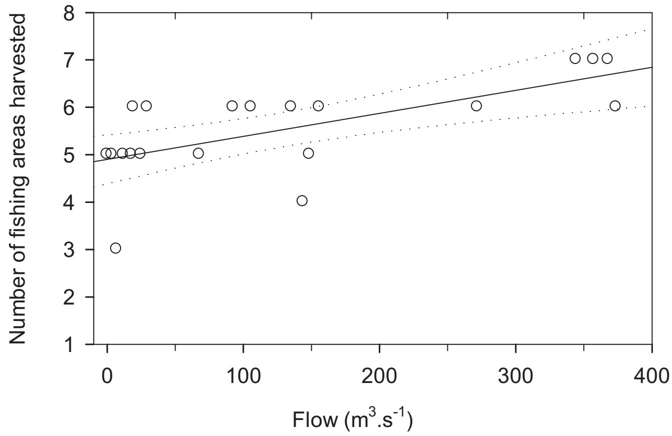

Fig. 7. Relationship between freshwater inflow to the Murray River estuary and the number of estuarine fishery reporting areas from which juvenile mulloway were harvested; 95% confidence intervals shown as dotted lines.

inflow and CPUE in the estuarine fishery which may have been partly attributable to changes in catchability in response to environmental conditions within the estuary. For example, prolonged periods of drought i.e. early 1980's and 2000's, may have caused hyper-stability of CPUE due to aggregation of juveniles in response to reduced area of protected, low salinity habitat (Ferguson 2008).

The life-history of *A. japonicus* is characterised by high maximum age with large size and high age at maturity, and may have evolved under low rates of natural mortality (Griffiths 1996). Juvenile *A. japonicus* show a preference for turbid estuaries with relatively high freshwater input in South Africa (Marais 1988; Griffiths 1996) and southern and south-eastern Australia (Hall 1986; Gray and McDonall 1993). This may reduce predation rates, particularly by con-specific adults, and increase growth rates (Griffiths 1996). It is likely that *A. japonicus* spawn in the nearshore environment in South Africa and South Australia (Hall 1986; Griffiths 1996) and that their adaption of a river-discharge spawning relationship enhances recruitment of juveniles to protected estuarine habitat.

We propose that that the remnant estuary of the Murray River provides important habitat for juvenile *A. japonicus* (0 to 5 years old) and that the population centred about the Murray River system is estuarine dependent, like populations of this species in South Africa (Griffiths 1996). The Murray River estuary may be particularly important habitat for *A. japonicus* because it is the largest area of protected estuarine habitat in southern Australia.

The population of *A. japonicus* in South Australia may be environmentally limited because high quality protected habitat is only available when there are prolonged, seasonal freshwater inflows into the Murray River estuary. The high turbidity and longitudinal salinity gradient preferred by juvenile *A. japonicus* (Marais 1988; Griffiths 1996) only occurs in years of prolonged freshwater inflows (Geddes 1987). Hence, conditions of high freshwater inflow may increase the area of estuarine habitat available to juveniles as suggested by the spatial breakdown of fishery catches i.e. catches are taken from higher numbers of fishery reporting areas in years when there is freshwater inflow to the estuary. Conversely, loss of estuarine habitat in drought years may lead to poor recruitment and possibly recruitment failure.

Failure of *A. japonicus* to recruit to the Murray River estuary may have occurred at least once in the previous three decades. Based on the absence of one year old *A. japonicus* in seine netting surveys in 1982, Hall (1986) postulated that the 1981 year class failed to recruit to the Murray River estuary. This coincided with drought conditions from 1979 to 1981, when the estuary became moderately hyper-marine, culminating in complete closure of the mouth of the Murray River in 1981 (Geddes 1987; Walker and Jessup 1992). Recruitment failure in 1981 is supported by; (i) the poor representation of individuals from year classes 1980 to 1985 , (ii) low catches from the estuarine fishery from 1984 to 1990, and possibly (iii) by the lack of a relationship between freshwater inflows and CPUE from 1984 to 2005.

Populations of *A. japonicus* are overfished in South Africa (Griffiths 1997) and new South Wales (Silberschneider and Gray 2008) and the population in South Australia may be vulnerable to a combination of habitat degradation and overfishing. Habitat degradation combined with high fishing mortality has been implicated in the decline of several populations of sciaenids, including totoaba, *Totoaba macdonaldii* and the Chinese bahaba, *Bahaba taipinhensis* (Cisneros-Mata et al. 1995; Sadovy and Cheung 2003). The totoaba in the Gulf of Mexico was placed on the Convention on International Trade in Endangered Species (CITES) list after the population declined from a combination of juvenile habitat loss following damming of the Colorado River, high levels of juvenile mortality resulting in recruitment overfishing, and targeting of the annual spawning aggregations (Barrera-Guevara 1990; Cisneros-Mata et al. 1995).

Our findings have implications for management of the fishery of *A. japonicus* in and near the Murray River estuary. In South Australia, *A. japonicus* occurs at the southernmost part of their global distribution where winter water temperatures are close to the lowest temperatures (12–28 °C) in which they occur (Bernatzeder and Britz 2007). The truncated age distribution, in combination with targeting of juveniles in a key nursery habitat (growth overfishing) and adults in a spawning/pre-spawning aggregation (recruitment overfishing) is likely to reduce the capacity of the population to withstand or recover from periods of prolonged habitat degradation through reduced freshwater flows. The relative rarity of sustained, seasonal freshwater inflows into the Murray River estuary has made this population extremely dependent on the presence of a few strong year classes resulting from years of above average flows. Future management of this fishery needs to consider the effects of environmental factors on the recruitment and survival of *A. japonicus* and the vulnerability of this species to increases in juvenile mortality and the targeting of pre-spawning aggregations.

The age distributions of *A. japonicus* from the nearshore fishery may also be a good indicator of the ecological status of the Murray River, because its reproductive success may be dependent on freshwater inflows, and because it is the apex predator in the Murray River estuary. In the northern hemisphere other Sciaenid species have been suggested as environmental indicators because of their habitat preferences and sensitivity to environmental variables. For example, spotted seatrout, *Cynoscion nebulosus*, has been suggested as an indicator of estuarine health for estuaries in North America (Burke et al. 1993; Bortone et al. 2005).

Acknowledgements. Funds for this study were provided by PIRSA Fisheries, SARDI Aquatic Sciences and the University of Adelaide. Fisheries statistics and library services were provided by SARDI staff and we thank Malcolm Knight, Angelo Tsolos, Emily Thompson, Annette Doonan, Suzanne Bennett and Craig Schillabeer for their help.

Commercial and recreational fishers provided access to samples from catches and SAFCOL provided bench space at the Adelaide Fish Market. Many otolith samples were obtained with help from SARDI staff, including Dr Qifeng Ye, Neil Wellman, Matt Pellizzare, Jason Higham, David Short, Tony Fowler, Paul Rogers, Paul Jennings, Richard Saunders, Alex Ivey, Simon Boxall and David Fleer. Bruce Jackson provided advice on cutting and mounting the otolith sections. Special thanks to Janet Pritchard (Environment Australia) who provided an otolith image from one of the the oldest *A. japonicus* recorded from the Murray River region. Also thanks to Joseph Davis and Kate Sandles from the Murray Darling Basin Commission for providing modelled flow data for the Murray River.

Helpful comments on the manuscript were provided by Paul Rogers, Adrian Linnane and two anonymous reviewers.

References

Anon., 1985, Improved catches of mulloway in the Coorong. South Australian Fisheries Industry Council (SAFIC) 9.

Barrera-Guevara J.C., 1990, The conservation of *Totoaba macdonaldi* (Gilbert), (Pisces: Sciaenidae) in the Gulf of California, Mexico. J. Fish Biol. 37, 201–202.

Beck M.W., Heck K.L. Able K., Childers D., Gillanders B.M., Halpern B., Hays C., Hoshino K., Minello T., Orth R.J., Sheridan P., Weinstein M., 2001, The identification, conservation and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51, 633–641.

Bernatzeder A., Britz P.J., 2007, Temperature preference of juvenile dusky kob *Argyrosomus japonicus* (Pisces: Sciaenidae). Afr. J. Mar. Sci. 3, 539–543.

Blaber S.J.M., 1980, Fish of the Trinity Inlet system of north Queensland with notes on the ecology of fish faunas of tropical Indo-Pacific estuaries. Aust. J. Mar. Freshw. Res. 31, 137–46.

Bortone S.A., Dunson W.A., Greenawalt J.M., 2005, Fishes as estuarine indicators. In: Estuarine Indicators. Bortone S.A (Ed.) Boca Raton, Florida, CRC Press, pp. 381–391.

Burke J.S., Peters D.S., Hanson P.J., 1993, Morphological indices and otolith microstructure of Atlantic croaker, *Micropogonias undulatus*, as indicators of habitat quality along an estuarine pollution gradient. Environ. Biol. Fishes 36, 25–33.

Cisneros-Mata M.A., Montemayor-Lopez G , Roman-Rodriquez M.J., 1995, Life-history and conservation of *Totoaba macdonaldi*. Conserv. Biol. 9, 806–814.

Close A.F. (Ed.), 1990, The impact of man on the flow regime. The Murray. Canberra, The Murray-Darling Basin Commission.

Farmer B., 2003, Biology of the mulloway *Argyrosomus japonicus* in Western Australia. School of Biological Sciences and Biotechnology. Perth, Murdoch University.

Ferguson G., 2006, The South Australian Lakes and Coorong Fishery: Fishery Stock Status Report for PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences) RD04/0099-2. 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) RD04/0099-2, pp. 1–12.

Ferguson G.J., Ward T., 2003, Mulloway (*Argyrosomus japonicus*) Fishery. South Australian Research and Development Institute (Aquatic Sciences) RD03/0040, pp. 1–55.

Geddes M.C., 1987, Changes in salinity and in the distribution of macrophytes, macrobenthos and fish in the Coorong lagoons, South Australia, following a period of River Murray flow. Trans. R. Soc. S. Aust. 111, 173–181.

Gillanders B., Kingsford M.J., 2002, Impact of changes in flow of freshwater on estuarine and open coastal habitats and the associated organisms. Oceanogr. Mar. Biol. Ann. Rev. 40, 233–309.

Gray C.A., McDonall V.C., 1993, Distribution and growth of juvenile mulloway, *Argyrosomus hololepidotus* (Pisces: Sciaenidae) in the Hawkesbury River, south eastern Australia. Aust. J. Mar. Freshw. Res. 44, 401–409.

Griffiths M.H., 1996, Life history of the Dusky kob *Argyrosomus japonicus* (Sciaenidae) off the east coast of South Africa. S. Afr. J. Mar. Sci. 17, 135–154.

Griffiths M.H., 1997, Management of the South African Dusky kob *Argyrosomus japonicus* (Sciaenidae) based on per-recruit models. S. Afr. J. Mar. Sci. 18, 213–228.

Griffiths M.H., Hecht T., 1993, Two South African *Argyrosomus* species: implications for management. Fish, fishers and fisheries- Proc. 2nd South African marine linefish Symposium, Oceanographic Research Institute.

Griffiths M.H., Hecht T., 1995, Age and growth of South African dusky kob *Argyrosomus japonicus* (Sciaenidae) based on otoliths. S. Afr. J. Mar. Sci. 16, 119–128.

Hall D., 1984, The Coorong: Biology of the major fish species and fluctuations in catch rates 1976-1983. South Australian Fisheries Industry Council (SAFIC) 8, 3–15.

Hall D.A., 1986, An assessment of the mulloway (*Argyrosomus hololepidotus*) fishery in South Australia with particular reference to the Coorong Lagoon. Department of Fisheries, South Australia, pp. 1–41.

Henry G.W., Lyle J.M., 2003, The National Recreational and Indigenous Fishing Survey. Fisheries Research and Development Corporation 99/158.

Hseih C., Riess C.S., Hunter J.R.,. Beddington J.R., May R.M., Sugihara G., 2006, Fishing elevates variability in the abundance of exploited species. Nature 443, 859–862.

Jones K., Doonan A.M., 2005, 2000-01 National Recreational and Indigenous Fishing Survey: South Australian Regional Information. Primary Industries and Resources SA 46, pp. 1–99.

Lenanton R.C.J., 1982, Alternative non-estuarine nursery habitats for some commercially and recreationally important fish species of south-western Australia. Aust. J. Mar. Freshw. Res. 33, 881–900.

Lenanton R.C.J., Potter I.C., 1987, Contribution of estuaries to commercial fisheries in temperate western Australia and the concept of estuarine dependence. Estuaries 10, 28–35.

Loneragan N.R. , Bunn S.E., 1999, River flows and estuarine systems: Implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland. Aust. J. Ecol. 24, 431–440.

Marais J.F.K., 1988, Some factors which influence fish abundance in South African estuaries. S. Afr. J. Mar. Sci. 6, 67–77.

McGlennon D., Jones, G.K., Baker J., Jackson W., Kinloch M.A., 2000, Ageing, catch-at-age and relative year-class strength for snapper (*Pagrus auratus*) in northern Spencer Gulf, South Australia. Mar. Freshw. Res. 51, 669–677.

Meynecke J., Lee S.H, Duke N.C., Warnken J., 2006, Effect of rainfall as a component of climate change on estuarine fish production in Queensland, Australia. Estuar. Coast. Shelf Sci. 69, 491–504.

Newman B., 2000, Hydrology of the Lower Lakes and Coorong. In: Jensen A., Good M., Tucker P., Long M. (Eds.), River Murray Barrages Environmental Flows: an evaluation of environmental flow needs in the lower lakes and Coorong. Adelaide, Wetlands Management Program, Department for Water Resources, pp. 1–118.

Robbins J.B., Halliday I.A., Staunton-Smith J., Mayer D.G., Sellin M.J., 2005, Freshwater flow requirements of estuarine fisheries in tropical Australia: a review of the state of knowledge and application of a suggested approach. Mar. Freshw. Res. 56, 343–360.

Sadovy Y., Cheung W.L., 2003, Near extinction of a highly fecund fish: the one that nearly got away. Fish Fish. 4, 86–99.

Scharf F.S., 2000, Patterns in abundance, growth, and mortality of juvenile red drum across estuaries on the Texas coast with implications for recruitment and stock enhancement. Trans. Am. Fish. Soc. 129, 1207–1222.

Silberschneider V., Gray C.A., 2008, Synopsis of biological, fisheries and aquaculture-related information on mulloway *Argyrosomus japonicus* (Pisces: Sciaenidae), with particular reference to Australia J. Appl. Ichthyol. 24, 7–17.

Thomas P.M., 1999, Water quality monitoring of Coorong Lagoons. Australian Water Quality Centre.

Walker D.J., Jessup A., 1992, Analysis of the dynamic aspects of the River Murray mouth, South Australia. J. Coast. Res. 8, 19–24.