Murray Cod
(*Maccullochella peelii peelii)*

Qifeng Ye, G. Keith Jones, and Bryan E. Pierce

November 2000

Fishery Assessment Report to PIRSA for the Inland Waters Fishery Management Committee

South Australian Fisheries Assessment Series 2000/17

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1. EXECUTIVE SUMMARY

Murray cod (*Maccullochella peelii peelii*) is one of the most important commercial and recreational species in the South Australian Inland Waters Fisheries. The cod fishery of South Australia has previously been described in general reviews of the River Fisheries by Rohan (1987) and Pierce and Doonan (1999). As the first fishery assessment report specific to Murray cod, this document reviews the current knowledge on the biology and fishery biology of this species, and provides information on biological performance indicators. These indicators are estimated either from compulsory catch and effort data or information collected voluntarily by commercial fishers, and include:

- Flow-adjusted catch rates from the commercial fishery,
- Intercept/return rate of cod returned to the water during the closed season, adjusted for flow rate, and
- The temporal changes in the size composition of cod during the moratorium and the closed seasons, as an indirect indicator of recruitment strength.

There was a moratorium on the taking of Murray cod by all sectors of the fishery between 1990 and 1993 inclusive within the South Australian section of the River Murray Basin.

The stock status of Murray cod is fully exploited. The commercial catch and effort has increased considerably in the last two years with the total landings of 19.0 and provisionally 15.4 tonnes in 1999 and 2000, respectively. The catch rates have also generally risen since 1996, which indicates that the floods in 1989 and the early 1990's have helped the stock to increase in size. However, the current fishery is mainly dependent on those few strong year classes with a relatively low number of recruits since then. These fish may remain in both the commercial and recreational fisheries for about another twelve years, and will become increasingly vulnerable if targeted effort increases by both sectors. Considering that there have been protracted years without significant floods of adequate water quality within the River Murray since 1994, there is a high risk that the stock will decline unless further strong year classes can be added.

In addition, further protection to the spawning stock biomass could be provided in the future by increasing the minimum legal size to 600 mm. It should be noted that this would have little impact initially as the abundance of fish below that size is currently very low.

Commercial data have been reasonably reliable although further research is needed in interpreting non-targeted effort for this species. Additional information on the intercept/return rate of Murray cod during the moratorium and seasonal closure and size measurements by volunteer commercial fishers are highly commended. This information has been shown to be particularly useful for an independent indicator of status of juveniles and the fished component of the Murray cod stock. However, lack of biological information (particularly age and growth) for SA populations have resulted in uncertainties. Moreover, further research is required to isolate environmental factors to adequately correct catch rates and improve the accuracy of biological performance indicators.

Commercial fisheries

- State landings of Murray cod have increased substantially since the lifting of the moratorium on the Murray cod fishery in 1994. The annual catches have been 19.0 and 15.4 tonnes in 1999 and 2000, respectively.

- The catch continues to be dominated by drum net, gillnet, and set line landings (about 98% total catch since 1985). Most of the effort by the first two gear types has been non-targeted whilst 97% of the set line effort has been targeting cod. Drum net effort has not changed markedly before and after the moratorium. However, there has been a dramatic increase in gillnet effort in the last three years, with catches peaking at 14.2 tonnes in 1999 and effort peaking at 7,232 netdays in 2000. Set line effort has declined significantly since the moratorium.

- The non-targeted catch per unit of effort (CPUE) by drum nets and gillnets, and the targeted CPUE by set lines generally decreased before the moratorium; however, the catch rates have recovered and increased notably since 1997 and have peaked in the last two years.

- The commercial fishery for Murray cod is dominated by the River Fishery, which has accounted for 94% of the total landings since 1985. Drum net catches are all from the River; so are set line landings, except for 1987 when minor catches (6% of set line catch) were taken from the Lakes. Although the Lake production had accounted for 62% of the total landings by gillnets in 1987 and 1988, in the other years since 1985, most of the gillnet catches have been harvested from the River, particularly since 1996.

- The flow corrected CPUE (CPUEFC) for drum nets and gillnets show a general trend of decline between 1985 and 1989. After the fishery reopened, the CPUEFC have increased dramatically since 1996, which indicates that the strong recruitment in Murray cod associated with spring flows in 1989 and the early 1990's has helped the stock to increase in size from its relative low state in the late 1980's.

Other monitoring

- Data collected by volunteer commercial fishers on intercept/return rates of Murray cod from drum nets during the moratorium and seasonal closure have also demonstrated increase return rates in recent years, although there are large fluctuations.

- Length data collected by volunteer commercial fishers since 1990 suggest that the current fishery is mainly dependent on a few strong size classes, which correspond to the floods in 1989 and the early 1990's. These fish have the potential to remain in the fishery for another twelve years.

- Few pre-recruits (<400 mm) have been evident since 1997, which may be associated with protracted periods without significant floods of adequate water quality since 1994. A reasonably high flow occurred in 1996 without a corresponding strong recruitment in that year. Even though water management

released adequate flows, it is likely that the water quality was inadequate and may have resulted in low recruitment success.

Recommendations

- The fishery is extremely vulnerable, as it is dependent on floods, habitat conditions, in addition to the presence of an adequate spawning biomass to ensure recruitment. Flow management to provide regular flooding of adequate water quality is strongly recommended to maximise the chance of breeding success for this species.

- In order to provide additional protection to the returning downstream migrating spawners, the retention of the extended seasonal closure (ie. September to December) is recommended.

- Ensuring that there is an adequate spawning biomass to maximise recruitment from good spawning years is an important strategy for the management of the Murray cod fishery. By raising the minimum legal size from the current limit of 500 mm to 600 mm, the reproductive potential for this species will be enhanced only when new strong year classes recruit to the breeding size range. An assessment is also required to establish the most biologically acceptable maximum size limit.

- The few year classes, on which the fishery currently depends, will continue to be vulnerable to gillnet fishing, especially if fishers adjust the mesh size of their gillnets to accommodate the growth of the strong year classes. Gillnet effort, mesh size, and catches should be closely monitored.

- There is currently no information on the selectivity of Murray cod in gillnets, or the level of incidental mortality caused by gillnets to fish outside the legal size. Given the significant increase in gillnet usage, these factors may be important to future management of this sector.

- Further research is required to investigate the significance of migratory barriers (both around Weirs and on/off the floodplain) and predation by exotic fish species on the cod populations.

- The commercial fishery represents only 35% of the total distance of the SA section of the River Murray. Assessment of the fishery is largely based on fishery dependent data and assumes that the commercial fishery is representative of the whole Murray cod population. Fishery independent sampling is required to test this assumption. In addition, it is necessary to monitor the Inland Waters recreational fishery on an ongoing basis in SA, as this sector has access to 100% of the river. An assessment of the illegal fishery is also necessary.

- Basic biological information (age, growth, mortality and reproductive biology) is required for the Murray cod populations in South Australia to strengthen future assessments and provide basic advice for management strategies.

- Further research is needed to isolate critical environmental factors, which influence recruitment strength and subsequent abundance.

2. BACKGROUND

2.1. Fishery

2.1.1. History

Murray cod support valuable commercial and recreational fisheries in South Australia. Historically, this species has dominated the Inland Water Fisheries for more than a hundred years (Rowland 1989). During the mid 1950's, the commercial catch in the River Murray in South Australia underwent a dramatic decline from over 140 tonnes in 1958/59 to 2 tonnes in 1975/76. From that time until 1989 catches remained below 10 tonnes, with the exception of 1978/79 and 1981/82.

Murray cod depend on flooding for successful recruitment, and given the low flood frequency it was felt that there was inadequate recruitment to maintain the population. As a result the fishery managers took a precautionary approach and imposed a moratorium on the taking of Murray cod in January 1990 within the South Australian sector of the River Murray Basin.

In the years following 1989, the lower river had regular annual floods, which it is believed, helped the stocks to rebuild (Pierce 1994). Consequently the Scalefish Management Committee decided to support limited harvest of Murray cod in SA, and the moratorium was lifted in January 1994.

2.1.2. Current fishery

The South Australian commercial fishery for Murray cod is primarily a river (reach) fishery, with the proportion of the total commercial catch from this sector ranging from 73-100% since 1985 (100% since 1996). The commercial catch of this species from the Murray Lakes (Alexandrina and Albert) is minimal, although it can increase during periods in which conditions in the river are poor.

The regional (River and Lakes) operations for commercial fishing and trends are further described later in this report.

There are three major types of commercial gear used to take Murray cod: set lines, gillnets and drum nets (termed "fyke nets" in standardised world gear nomenclature). These three methods have accounted for 98% of the total catch since 1985.

Set lines are multiple hook lines baited and set almost invariably near a snag of some description. Until 1998, set line had been the most popular gear for targeting Murray cod. In 1999 and 2000, gillnets became the dominant gear for targeted effort. Additionally, Murray cod are often caught in drum nets when targeting callop during the high flow seasons. In fact, this non-targeted catch from drum nets has accounted for 41% of the total commercial landings since 1985.

Cod are very vulnerable during clear water conditions. Pierce (1994) reported that in the 1960s, relatively large numbers of cod were taken on trolled lures such as the

infamous 'floppy' and aeroplane spinners; since that time, irrigation flows from up river have maintained turbid water, preventing such fishing conditions.

The peak seasons for cod fishing are autumn and winter. During these high flow periods, the fish are very active and feeding intensively in preparation for winter and the spring spawning.

2.1.3. Management

In South Australia, the commercial River Murray fishery is managed as a separate fishery under the *South Australian Fisheries Act, 1982*. It is defined in the *Scheme of Management (River Fishery) Regulations, 1991* as the River Murray and its anabranches, tributaries and lagoons situated upstream of the punt which services the main road joining the township of Wellington to the township of Wellington East (Presser 1996). The fishery is limited entry, with 30 owner-operators having limited, exclusive commercial access to resources within particular specified areas (termed "Reaches") (Knight *et al.* 2000). These reaches cover around 35% of the South Australian sector of the River Murray. Cod are territorial; therefore, they live in "refuge" from the commercial fishery for over 65% of the river system in the state. Commercial effort is limited through gear entitlements as designated in the current fisheries management plan. Each licence holder is limited to using not more than 50 units of scalefish fishing gear at any time (Fisheries Licence Conditions, PIRSA).

One unit of scalefish fishing gear is defined as:	
Either	*1 drum net,*
Or	*1 set net,*
Or	*1 bait net,*
Or	*10 set line hooks.*

A gear unit system was introduced around September 1999, which further limits the number of gillnets that can be used to 30. The introduction of this system reduced the potential number of gillnets available for use in the fishery by 40% from 1500 to 900 nets. The implementation of the gear unit system and the removal of access to native fish in backwaters by commercial fishers formed part of the recommendations made by the Environment, Resources and Development Committee.

The use of gillnets varies in different sections of the river, however they are important for the taking of carp and Bony bream in the backwaters of the River Murray. Gillnets are also used for the taking of native species in the mainstream of the River Murray, and are particularly important for the taking of callop and Murray cod when the river flows are low. Under licence conditions, the commercial fishers must not use gillnets with a mesh size of less than 100 mm and more than 150 mm, and a length of more than 50 metres. Drum nets, which are also a regularly used commercial fishing device, are significantly less efficient during periods of low river flow.

The commercial Lakes Fishery is limited entry, with 38 owner-operators having non-exclusive access to resources within the entire Lake Alexandrina/Albert system (Knight *et al.* 2000). Effort is limited through gear entitlements as designated under the Lakes and Coorong Fishery Scheme of Management (Pierce and Doonan 1999).

The recreational fishery is open access with an estimated 160,000 participants annually for the entire inland resource in SA, of which the River Murray component is by far the most popular and targeted (Pierce and Doonan 1999). Recreational access is determined by the *Fisheries (General) Regulations, 1984*.

Since January 1994, a legal minimum size of 500 mm and a legal maximum size of 1100 mm total length have applied to all Murray cod landings in South Australia. In addition, there is a closed season from 1st September to 31st December inclusive. Recreational effort is further regulated by a bag limit of two cod per fisher per day, with gear restrictions including two rod/handline limits and "in attendance" requirements. Prior to the moratorium (January 1990 to December 1993), there was only a minimum size limit of 460 mm and a three-month seasonal closure between 1st September and 30th November.

2.2. Management Objectives

According to the *SA Fisheries Act, 1982* (*Part III Administration, Division I - Objectives. Section 20*), the principal management objectives are:

- ensuring, through proper conservation and management measures, that the living resources of the waters to which this Act applies are not endangered or over-exploited; and
- achieving the optimum utilisation and equitable distribution of those resources.

The River Fishery Management arrangements were approved by government in September 1989 (Presser 1996), with the specific objectives to:

- actively pursue improvements to the fishery habitat and stock recruitment;
- provide increased protection for existing fish stocks;
- share fairly the burden of adjustment for reducing fishing effort;
- maximise community benefits from the available fish stocks; and
- make best use of available management resources for the fishery.

2.3. Biology

2.3.1. Taxonomy and stock structure

Murray cod (*Macculochella peelii peelii*) belongs to the family Percichthyidae, which has about 25 genera, including freshwater, estuarine, catadromous and oceanic species. In two of the genera, there are five species found purely in Australian fresh waters, and two are more or less catadromous, spawning in marine waters (Harris and Rowland 1996). The three species within genus *Maccullochella* are eastern cod (*Macculochella ikei*), trout cod (*Macculochella macquariensis*), and *Macculochella peelii*. The former two are listed as endangered species by the Australian Society for Fish Biology (Harris and Rowland 1996).

There are two subspecies within *Maccullochella peelii*, which are the Murray cod (*Macculochella peelii peelii*) and the Mary River cod (*Macculochella peelii*

mariensis). The Mary River cod is endemic to the Mary River system in south-eastern Queensland (Harris and Rowland 1996). It was once extremely abundant but has dramatically declined with the natural population restricted to the waters of 3-5 small tributaries. It is now classified as endangered by the Australian Society for Fish Biology.

Murray cod constitute one genetic stock throughout the Murray River system in South Australia (Pierce and Doonan 1999).

2.3.2. Distribution

Murray cod is the largest freshwater fish in Australia. Its natural distribution is widespread throughout most of the Murray-Darling system except for the upper reaches of some tributaries in Victoria and southern New South Wales (Lake 1971). Murray cod were originally extremely common and supported a substantial commercial fishery in the nineteenth century and in the early decades of the twentieth (Rowland 1989). Extensive flow regulation and habitat modification of the majority of the rivers in the Murray-Darling basin have resulted in a great reduction in Murray cod abundance throughout its range since the 1950s (Reynolds 1976, Cadwallader 1978, Cadwallader and Gooley 1984, Rowland 1989, Walker and Thoms 1993). This species is currently classified as vulnerable according to the Conservation Status Classification by the Australian Society for Fish Biology (Jackson 1993).

Murray cod have been stocked into many waters outside its natural range in lakes, reservoirs, farm dams, and rivers (Morrissy 1970, Rowland 1989). Some re-stocking has occurred to enhance the river population. However, the most important tool in restoring cod populations is the appropriate management of the river systems.

2.3.3. Habitat

The habitat of Murray cod varies greatly from small clear rocky streams in the upper western slopes of New South Wales to the generally turbid, slow-flowing rivers and creeks of the western plains (Harris and Rowland 1996). Small cod appear to move more through the river system, however, as they become larger they tend to select a particular part of the river and remain there (Lantry, in Cadwallader 1977). Adult cod do not undergo extensive migration; during turbid conditions they show little tendency to move far from their "home" structure either at night or during the day (Reynolds 1983). However, recent radio tagging study in Victoria has demonstrated that cod do migrate significantly during September and December; they move upstream up to 80-100 km to spawn, then return to the original snag which is their home range/habitat (unpublished data, Koehn 2000). Murray cod are generally found in or near deep holes and prefer habitats containing cover such as rocks, fallen trees, stumps, and clay banks or overhanging vegetation (Harris and Rowland 1996). They are very territorial, and aggressively attack any fish, including other species, entering the area (Pierce 1994).

2.3.4. Reproduction

Murray cod are known to spawn during spring and early summer, depending on prevailing climatic conditions, in response to increasing day length (photoperiod) and

water temperature (Lake 1967; Lantry, in Cadwallader 1977, Rowland 1983, 1985, Gooley *et a*l., 1995). Rowland (1985) provided the most comprehensive data on various aspects of the reproduction of Murray cod captured from sections of the Murray-Darling basin. He reported that "cod are very active before spawning, possibly associated with increased feeding, mating and spawning site selection; large (3mm) adhesive eggs are deposited onto solid surfaces such as logs, rocks or clay; relative fecundity is around 5000 eggs/kg; the male protects and probably fans the eggs during incubation, and hatching commences 5 days after fertilisation and lasts about 4 days at 20-22 °C; the larvae which are 8 mm in length, have a large yolk sac, and remain clumped for up to 11 days before they disperse and commence feeding on zooplankton" (Rowland 1985).

He found that relatively strong year classes were only established when the breeding seasons coincided with high river levels or floods. Floods occurring in October and November provide optimum conditions for the survival and recruitment of *M. peelii* larvae (Rowland 1989).

Pierce (1994) further suggested that, in the South Australian section of the Murray, female cod do not necessarily spawn each year; they re-absorb their eggs during non-flood years to give their off-spring the best chance of survival during the best feeding conditions; large numbers of fry are only produced in flood years.

The size and age of Murray cod at first maturity are extremely variable, depending on a range of factors including ambient climatic conditions and natural productivity of the water (Rowland 1985, Gooley *et al.* 1995). The various estimates of mature size and age are shown in the following table:

Table 1. The size/age at first maturity of Murray cod from different regions in Australia.

Sex	Total length (mm)	Weight (kg)	Age (years)	Maturity status	Region	Reference
Both	381	1.14	NA	first	South-western N.S.W.	Whitley (1937)
Both	432 457 483	NA	NA	first 50% 70%	Bringagee, Victoria	Langtry, in Cadwallader 1977
Both	560	1.8-2.3	4	first	N.S.W.	Lake 1967
Female Male	610 625	5.0 5.4	4 4	first first	Lake Mulwala, NSW	Rowland 1985
Female Male	480-590 530-585	2.1-3.9 2.3-3.4	4-5 3-5	first first	Murray, Edward, Wakool, Murrumbidgee and Gwydir Rivers, NSW	Rowland 1985
Female Male	500 400	2.0 0.7	6 3-4	first first	Lake Charlegrark, Victoria	Gooley *et al.* 1995

Based on histological analysis, Gooley *et al.* (1995) first documented three intersex fish, which were macroscopically classified as female.

2.3.5. Age and growth

Murray cod is Australia's, and one of the world's largest freshwater fish. Whitley (1955) stated that Murray cod grows up to 1800 mm and 83 kg. There was a newspaper report of a 113.6 kg cod being caught in the Barwon River near Walgett (New South Wales) in 1902 (Noble 1955). Although cod larger than 50 kg are rarely captured, small numbers of cod between 20 and 40 kg are regularly taken by experienced commercial and recreational fishermen (Rowland 1989). Most of the fish caught are now less than 10 kg (Harris and Rowland 1996).

Various attempts have been made to age Murray cod using bony structures (Llewellyn 1966). However, the earlier studies were either unvalidated or based on few individuals (Roughley 1966; Lake 1967; Jones 1974; Langtry, in Cadwallader 1977).

Rowland (1985) provided more substantial data on the growth of Murray cod, caught from six rivers and two impoundments in southern New South Wales. He used whole sagittal otoliths and operculae to age 330 Murray cod, up to 1270 mm length and 40 kg weight. The method was validated by using known-age fish up to 3 years old as well as marginal increment analysis for pooled age/classes. Operculae were used for larger fish because reading whole otoliths was found to be unreliable for cod larger than 800 mm (about 8 years old) (Rowland 1985). The oldest estimated age he obtained was 34 years (1250 mm, 36 kg).

Gooley (1992) used broken, burnt and polished half sagittae from 231 Murray cod from an isolated population in Lake Charlegrark, south-western Victoria, to provide a validated method for Murray cod up to 11 years old. The method was validated by using known age fish up to 4 years old, seasonal changes in marginal increments, and modal progression of strong year classes in Lake Charlegrark. The oldest estimated age was 21 years at about 820 mm.

Anderson *et al.* (1992) studied the age and growth of Murray cod in the lower Murray-Darling basin, including the River Murray and its Victorian and Southern New South Wales tributaries, from thin transverse-sectioned sagittae of 290 cod up to 1400 mm in total length and 47.3 kg in weight. The maximum age estimated was 48 years. This method was validated by comparing age estimates with 55 Murray cod from Lake Charlegrark (age 0-21 years), which had been validated by using burnt and polished half-otoliths. It had an accuracy of 96.4% and offers major advantages in ease of preparation, reading, and batch-handling of large numbers of otoliths.

The average growth rate of Murray cod has been estimated in New South Wales rivers as 236, 348, 500, 580, and 640 mm in total length at year one to five respectively (Harris and Rowland 1996). In Lake Mulwala, cod of 4 years old average 654 mm in total length (5.8 kg) (Rowland 1985) but only 427 mm (1.8 kg) (Gooley 1992) in Lake Charlegrark. Pierce (1994) reported that in South Australia, one cod born in the 1974 flood was tagged in 1979 and grew to 38.5 kg at 17 years whilst cod of 34 kg were found to be about 25 years old in New South Wales. In general, cod grows mostly by increase in weight when older than 10 years (Harris and Rowland 1996).

Growth patterns and body forms of Murray cod may vary significantly for populations from different regions and different habitats within the Murray-Darling Basin (Rowland 1985, Anderson *et al.* 1992). Lake (1967) suggested that difference in

growth rates might be partially explained by the earlier spawning times of Murray cod in the northern part of its distribution, allowing for greater growth in the first year that could be retained in the later years. Rowland (1985) and Anderson *et al.* (1992) found that cod from impoundments (Mulwala, Lake Burrinjunk, and Lake Charlegrark) were significantly heavier at a given length than cod taken from riverine habitats. Further detailed work is needed to study the variation in growth pattern of Murray cod throughout its distribution and the factors that influence growth rates and body form in different habitats (Anderson *et al.* 1992).

There are similar growth rates of male and female cod up to 34 years old (Rowland 1985 and Gooley 1992). However, when including larger average size individuals in the study (up to 39 years old), Anderson *et al.* (1992) suggested that sex-related differences might become apparent only in larger and older fish. The males have a faster growth rate in length than the females; however, the females tend to be heavier than the same sized males.

2.3.6. Diet

Murray cod is the top predator in inland waters and is at times a voracious feeder; their diet consists of fish, crustaceans, molluscs, water birds, turtles, frogs, and some terrestrial animals, including snakes and mice (Lake 1967, Lantry, in Cadwallader 1977, Harris and Rowland 1996). Cod ingest virtually anything within its realm that moves and is small enough to fit in its cavernous mouth (Pierce 1994).

Lake (1967) suggested that small cod less than 100 mm eat smaller forage species such as the western carp gudgeon and Australian smelt. The survival of cod is largely conditioned by the success of breeding of these forage species. Rowland (1992) studied the diet of Murray cod larvae. He reported that cod larvae commence feeding on zooplankton at the completion of yolk sac absorption, 9 to 11 days after hatching at water temperatures of 20-22°C; zooplanktons ranged in length from 180-450 μm. In earthen ponds, larvae fed mainly on the calanoid copepods and the cladocerans for two weeks; then chironomid larvae and aquatic insects became the major components of their diet. He also found that a delay in initial feeding could significantly reduce the survival rate of larvae.

3. STATUS OF THE STOCK

3.1. Previous Assessments

The Murray cod fishery has previously been described by Rohan (1987) and Pierce and Doonan (1999). Rohan (1987) provided a review of management arrangements of River Fishery in South Australia. He reported on the State commercial catch levels between 1951 and 1985 for the major species including Murray cod in the River Fishery. An assessment of fish abundance was conducted based on the commercial catch data only. Rohan (1987) indicated the decline of the Murray cod catch and suggested that spawning and recruitment of cod in South Australian waters had been poor in the 1970s. Murray cod was considered to be at risk in the long term (Glover 1987). As the predicted environmental changes were likely to moderate rather than enhance natural recruitment, it was proposed that total fishing effort be reduced for certain fish stocks, particularly Murray cod (Rohan 1987).

Pierce and Doonan (1999) developed a summary report on the status of selected species in the River Murray and Lakes and Coorong Fisheries. For each species, including Murray cod, information has been summarised on the stock structure, and characteristics of the fishery. The trends in the commercial catch by species, total fishing effort by gear, catch per unit effort (CPUE), and abundance of pre-recruits were also discussed for the period between 1984/85 and 1997/98. The production status for Murray cod was unknown and the sustainable harvest status for this species was described as fully exploited.

3.2. Review of Fisheries

Historical commercial fishery data including Murray cod have previously been presented by Rohan (1987) and Pierce and Doonan (1999) in their reviews of the status of inland water species. This is the first stock assessment report specific for Murray cod in South Australia, which updates commercial catch and effort information for this species since those reports and provides a more detailed discussion and overview of trends within the Murray cod commercial fishery up to August 2000. The information predominantly relates to the River, as the Lake fishery for Murray cod is minor in SA. Commercial fishing activity varies significantly between the river and the lakes. A map showing the geographic locations of the River and Lakes for the Inland Waters Fisheries in SA is presented in Fig 1 on the following page. In addition, there are two ecologically distinct sections within the River system, the floodplain and the gorge. Geographically, the river section to the east of Cadell Fault is defined as floodplain; and to the south-west of Cadell Fault is defined as gorge (Fig 1). Unfortunately, detailed comparisons for the fisheries cannot be made between these two sections, as this would breach confidentiality arrangements on production data. At the time of this report, data presented for July and August 2000 were provisional. A calender year is used as the major time unit in the fishery assessment as this is most consistent with the biology and management arrangements for Murray cod.

Fig 1. Map of the River Murray and the lakes for the Inland Waters Fisheries in SA.

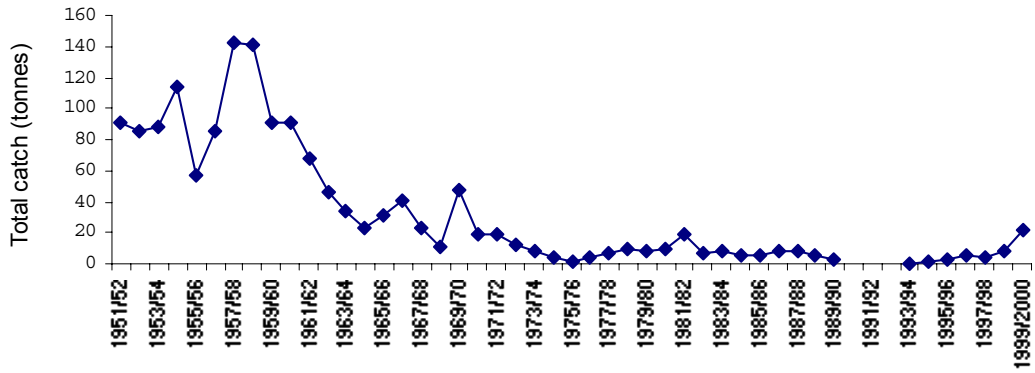
3.2.1. State overview

3.2.1.1. Annual catch

The State commercial catch of Murray cod declined dramatically through the 1960s from the level of 140 tonnes in the end of 1950's to an average below 10 tonnes per annum in the early 1970's (Fig 2). The annual landings remained under 10 tonnes (except for 1981/82) and a moratorium was instituted in 1990. The fishery recommenced in 1994. Since then, the landed catch of Murray cod has increased gradually to a relatively high level of 21.3 tonnes in 1999/2000.

As catch information before 1975/76 was only provided by SA fish processors in financial years, the State catches are presented in a financial year basis in order to show the overall trend since 1951/52 (Fig 2). Furthermore, we assume that no fish were harvested in the closed season (September to November) before 1975/76. Unfortunately, no figures on catch by gear type are available before 1983/84 so only the total catches can be presented (Fig 2). More detailed information is available since 1985, which allows for analyses of catch, effort, and catch per unit effort (CPUE).

Fig 2. Murray cod commercial landings in Reach and Lakes and Coorong Fisheries, SA 1951/52 to 1999/2000.



3.2.1.2. Annual value

Although Murray cod catch represents only a small percentage of the total commercial inland waters harvest by weight, it contributes a significant return to the River Fishery due to its high value. Although not adjusted by inflation rate, the average landed price of Murray cod (whole fish) has increased dramatically from $ 4.98/kg in 1985 to $ 15.84/kg in 1998 (more than trebled) (Fig 3). The rise has been more abrupt since the lifting of the moratorium in 1994, disregarding the fluctuations in the total production. The value of the total catch peaked at $101,000 in 1998, a year of only average landings (Fig 4). The substantial average price rise has resulted in the rapid increase in the total value of this species. In 1999 and 2000, the commercial landings climbed to much higher levels (19.0 and 15.4 tonnes, respectively); however, as price information is not yet available for these last two years, corresponding values cannot be presented.

It needs to be noted that the price data have been provided by the South Australian fish markets except the mean price for the second six months of 1998 ($13.75/kg) was based on the Victorian fish market averages as the local market showed an abnormally low value of approx $5.00/kg for this period. Baker and Pierce (1998) conducted a reassessment of the gross economic value of South Australian commercial inland fisheries harvest. They suggested that as much as 99% of the Murray cod catch was sold interstate for average prices approximately 60-70% higher than the Adelaide price. Therefore the values presented in Fig. 3 should be lower than those actually received by the fishers from the interstate markets. Without incorporating interstate prices into the calculation, the value of the cod catch was underestimated by approximately 43% in 1996/97 (Baker and Pierce 1998).

Fig 3. Average price per kilogram in the Adelaide market for Murray cod from 1985 to 1998.

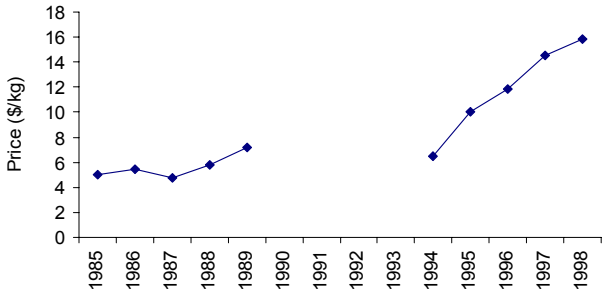
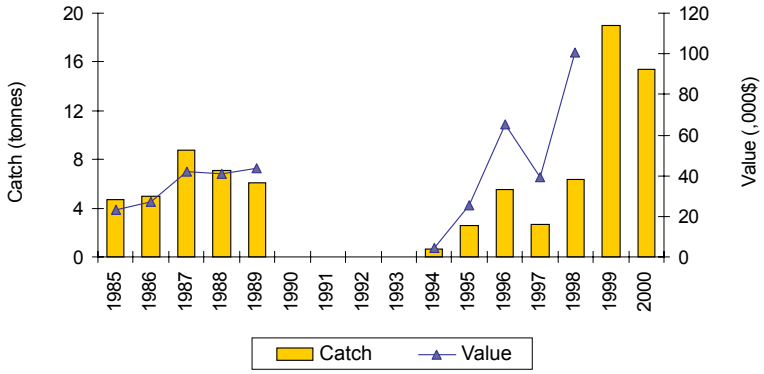


Fig 4. Murray cod commercial catches and value in Reach and Lakes and Coorong Fisheries, SA 1985 to 2000.

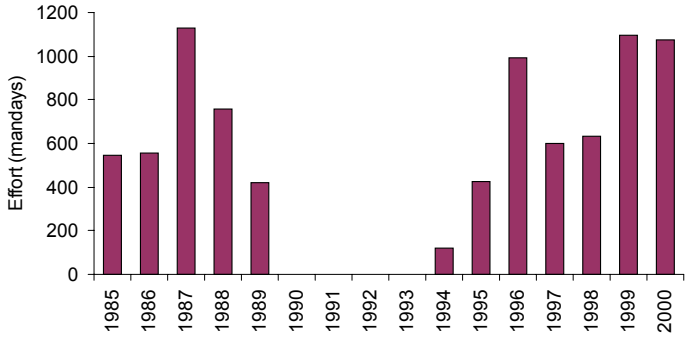


3.2.1.3. Annual effort

Target and non-target effort is only reported from 1985 onwards through detailed catch return forms from commercial fishers (Appendix I). Effort has been recorded in both mandays and geardays. All data have been computer validated and do not take into account information not received or processed by SARDI Information and Statistics Unit. Information may be altered or updated by this unit without notice including different methodologies for data extraction and interpretation.

As the River Murray is by nature a massively variable system, the overall commercial fishing effort for Murray cod has differed greatly from year to year (Fig 5), ranging between 121 and 1,094 mandays. Fishing effort has increased significantly since the lifting of the moratorium in 1994, with total commercial effort peaking at 1,094 and 1,074 mandays in 1999 and 2000, respectively. In general, fishers increase their effort for cod (and other species) when conditions are favourable for their capture and stocks are healthy, rather than being a strict function of price or available capacity.

Fig 5. The total commercial effort (mandays) (both targeted and non-targeted) for Murray cod in SA 1985 to 2000.



3.2.1.4. Seasonality of catch, effort and CPUE

There is a strong intra-annual seasonality in average catch and effort for Murray cod. The catch increases steadily from a low in January (335 kg) to a peak in August (2528 kg) before the seasonal closure (September to December, inclusive) (Fig 6). The significant catch in August contributes more than a third (35%) to the total annual landings. Mean catch in December was only based on the fishery data between 1985 and 1989 when the seasonal closure was only for three months (September to November, inclusive). The average catch drops in December to about the same level as that in January.

The average effort increases steadily over the first five months from 32 mandays in January to 107 mandays in May (Fig 6). It declines slightly (about 10%) in June and July before jumping to the peak of 163 mandays in August. Effort in December declines to 40 mandays.

The monthly pattern of average CPUE (kg/manday) closely follows the seasonal flow (Fig 7). Highest flows usually occur between September and November, which coincides with the spawning season for Murray cod. During this period, Murray cod are protected by the seasonal closure (September to December) in SA. The December closure has been set since 1994 to protect the downstream migrating cod returning to their home territories after spawning.

Fig 6. Seasonality of average monthly catch and effort for Murray cod in SA 1985 to 2000.

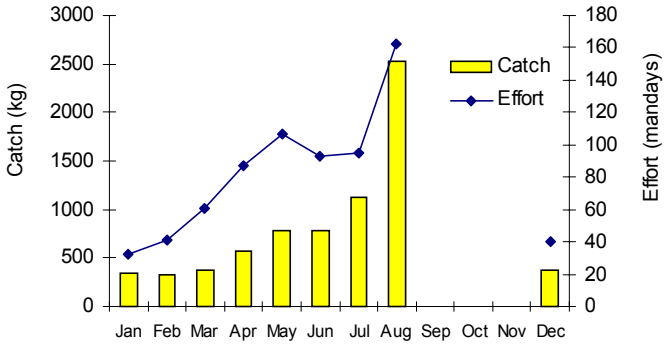
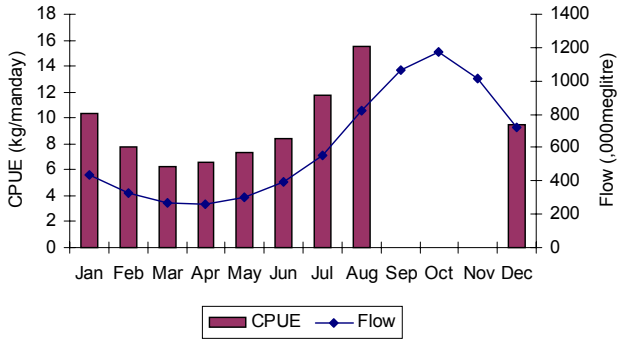
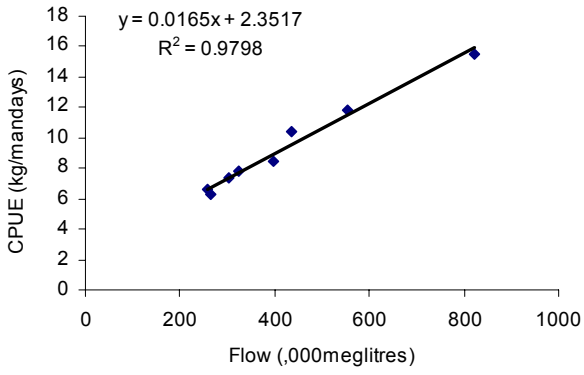


Fig 7. Seasonality of average monthly CPUE for Murray cod and average flow in SA 1985 to 2000.



There is a close linear relationship between catch rate and flow discharge (R^2=0.98) (Fig 8), which indicates that river flow has a direct positive influence on catchability. For example, drum nets only catch well when the river flows well (Rohan 1987). Studies have suggested that Murray cod tend to be more active under the high flow conditions (Rowland 1985).

Fig 8. The relationship between the average monthly flow and CPUE for Murray cod (January to August) from 1985 to 2000.



3.2.1.5. Catch, effort, and CPUE by gear type

3.2.1.5.1. Total catch and effort by gear type

The landings from drum nets, set gillnets, and set lines contribute most to the overall Murray cod catch in this state, with more than 95% of the annual catch taken by these three methods since 1985 except for 1987 (Table 2). The remainder of the State catch is taken by handlines, mullet nets, and other gears. After the moratorium, all commercial landings have been by three major methods only. For reasons of confidentiality, set line catches for 1989, 1996, 1997, 1998 and 1999 are not presented.

Table 2. Murray cod annual commercial catch by fishing method in SA 1985 to 2000.

Year		1985	1986	1987	1988	1989	1994	1995	1996	1997	1998	1999	2000
Gear													
Drum net	tonnes	**1.12**	**2.92**	**2.27**	**3.16**	**5.55**	**0.36**	**1.94**	**4.72**	**1.30**	**0.99**	**4.56**	**5.46**
	%	23.8	58.7	25.9	44.3	91.0	55.5	76.5	85.6	48.0	15.5	24.0	35.4
Gill net	tonnes	**2.91**	**1.13**	**2.15**	**2.27**	**0.47**	**0.16**	**0.30**	**0.61**	**1.21**	**5.02**	**14.24**	**9.89**
	%	62.0	22.7	24.6	31.9	7.6	25.5	11.8	11.1	44.9	79.0	74.9	64.1
Set line	tonnes	**0.44**	**0.89**	**3.20**	**1.45**	*	**0.12**	**0.30**	*	*	*	*	**0.07**
	%	9.5	18.0	36.6	20.4	*	19.1	11.7	*	*	*	*	0.5
Grand Total	tonnes	**4.69**	**4.98**	**8.75**	**7.13**	**6.10**	**0.64**	**2.53**	**5.51**	**2.70**	**6.35**	**19.00**	**15.43**

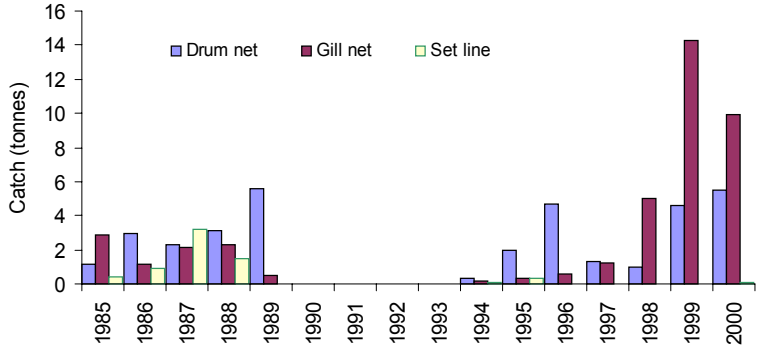
*Confidential information

On average, the commercial catch by drum nets accounts for 41.0% of the State landings of Murray cod. The catch has fluctuated between 0.4 and 5.5 tonnes since 1985 with no significant difference before and after the moratorium (Fig 9). There was a trend of increasing catch before the moratorium, peaking in the flood year of 1989. The annual catch has fluctuated more after 1994, with several large landings in 1996, 1999, and 2000.

The gillnet sector accounts for 48.2% of the total landings. There has been a substantial increase in gillnet catch since 1998, peaking with 14.2 tonnes in 1999 (Fig 9). Although the landing dropped by 31% to 9.9 tonnes in 2000, it has still been the second highest catch since 1985. In the past three years, gillnets contributed 64-79% of the overall catch of Murray cod in SA.

The third gear type the set line has accounted for about 9% of the total commercial harvest since 1985. The annual catch by this method has been generally low, remaining less than 1 tonne per annum except for 1987 and 1988 (Fig 9). Catches have further reduced after the moratorium, with a landing of only 70 kg in 2000.

Fig 9. Murray cod annual commercial catch by three major fishing methods in SA 1985 to 2000.

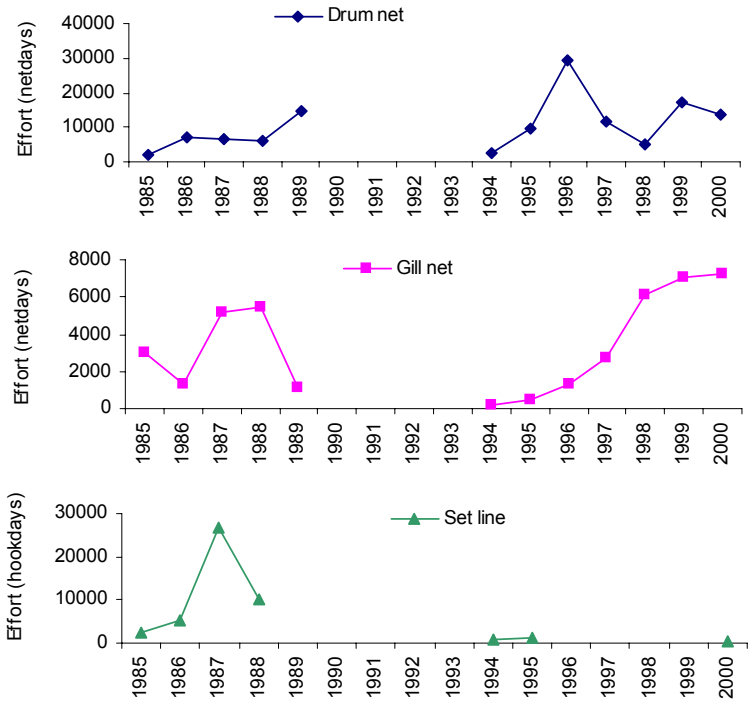


Trends in annual fishing effort (both targeted and non-targeted) since 1985 are shown for drum nets, gillnets and set lines in Fig 10. Drum net effort has fluctuated dramatically between 1,778 and 29,455 netdays. The effort had more than doubled in 1989, a major flood year, compared to previous years. After lifting the moratorium on cod harvest in 1994, it quickly rose to an extreme peak in 1996, a relatively high flow year, before declining to a low of 5018 netdays in 1998. The drum net effort climbed back to 17,425 and 13,676 netdays in 1999 and 2000, respectively. As drum nets work effectively in flow conditions, high effort generally occurred in high flow years, such as in 1989 and 1996.

In contract to drum nets, gillnets are important for the taking of Murray cod when the river flows are low, as gillnets weed up in flows and become unfishable. These explain the shift of effort between drum net and gillnet sector based on flow conditions. Gillnet effort has increased significantly since 1994, to a peak of 7,232 netdays in 2000. Despite the introduction of gillnet unit system in September 1999, which has potentially decreased the number of gillnets by 40%, gillnet effort in 2000 remained at a similar level to that in 1999.

There has been a considerable reduction in set line effort since the end of the moratorium. We believe that as fishers have become more mobile in recent years, engaging in several activities for incomes, many of them have shifted to use drum nets and gillnets, the methods with higher return for effort. It is also believed that there has been a loss of skill in this gear type as older fishers have left the fishery. Detailed effort cannot be provided for 1989, 1996, 1997, 1998 and 1999 due to confidentiality (less than five fishers active in the set line fishery).

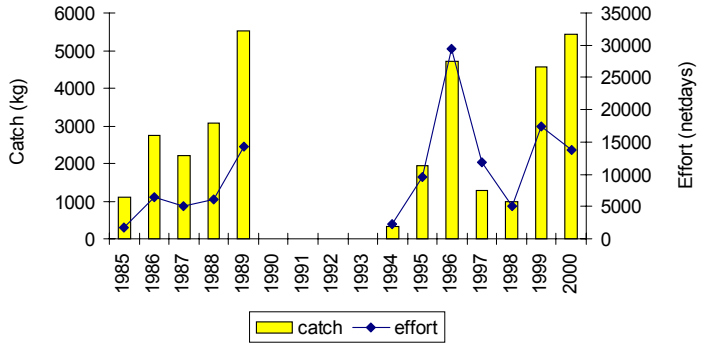
Fig 10. Murray cod annual commercial effort by gear type in SA 1985 to 2000.



3.2.1.5.2. <u>Targeted and non-targeted catch, effort, and CPUE by gear type</u>

Only 22% of the overall State Murray cod catch has been from targeted fishing since 1985, and these were mainly from set lines and gillnets. Almost all the drum net catches (99%) for Murray cod have been from non-targeted effort. Cod were often landed in drum nets when fishers were targeting callop or "ANY" species. Therefore non-targeted catch and effort basically show the same patterns (Fig 11) as the overall drum net fishery since 1985 (Figs 9 and 10). The catches in the last two years are among the highest since 1985 even though the effort is only slightly higher than the annual average.

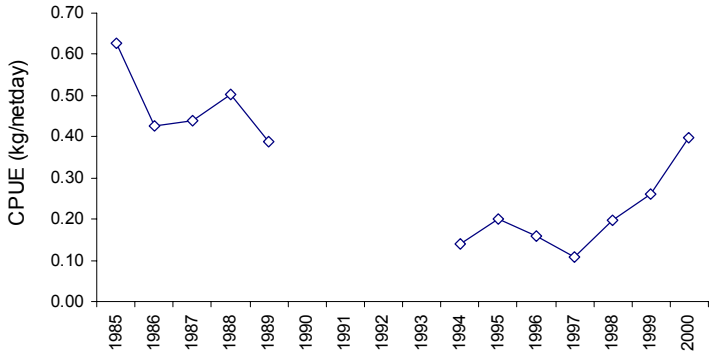
Fig 11. Non-targeted catch and effort for Murray cod by drum nets 1985 to 2000.



Non-targeted CPUE in the drum net sector had declined from 0.63 kg/netday in 1985 to 0.39 kg/netday in 1989 (Fig 12). Although the catch rates were apparently higher

before the moratorium, it must keep in mind that there has been a change in the fishing regulations for Murray cod since 1994, when an increase of the minimum legal size limit from 460 mm to 500 mm, a maximum legal size limit (1100 mm), and an extension of the seasonal closure to four months were proclaimed. After the fishery re-started in 1994, the CPUE had remained at relatively low levels of 0.11-0.20 kg/netday till 1997; however, since then, the catch rate has increased steadily to 0.40 kg/netday. As flows can strongly influence catchability (Fig 8), CPUE needs to be evaluated in conjunction with environmental factors (eg. flow and water quality) before indicating the relative stock abundance. This also applies to the gillnet fishery. Details of the relationships between catch, effort, CPUE and river flow, and flow corrected CPUE will be further discussed by gear type for the River Fishery in Section 3.2.2. *Regional catch and effort*.

Fig 12. Non-targeted CPUE for Murray cod by drum nets 1985 to 2000.



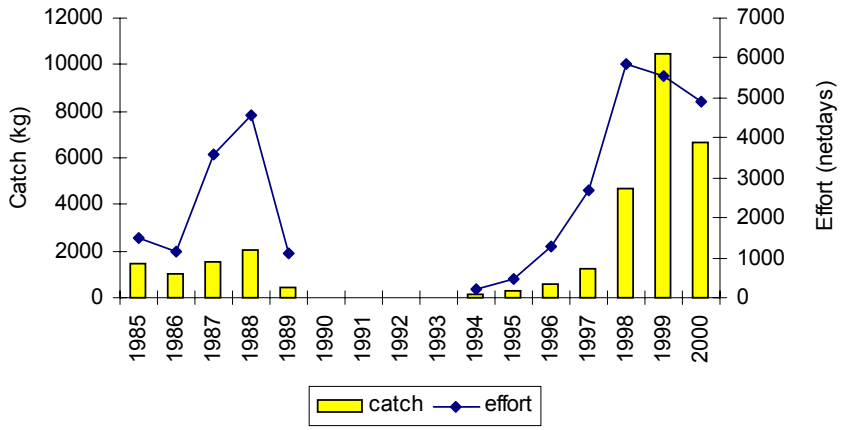
On average, only 24% of the total gillnet landings and 20% of the effort has been targeted on Murray cod since 1985. Detailed targeted catch and effort by gillnet can only be provided for 1986, 1987, 1999, and 2000 due to fishery confidentiality (Table 3). In 1987, most of the targeted catch (96%) by gillnet was from the lakes. There has been substantial increase in targeted catch and CPUE in 1999. However, the targeted catch has dropped 14% even though effort has risen 48% in 2000.

Table 3. Targeted catch effort and CPUE for Murray cod by gillnets in 1986, 1987, 1999 and 2000.

Year		1986	1987	1999	2000
Catch	kg	72	588	3764	3226
Effort	netdays	151	1633	1566	2314
CPUE	kg/netday	0.48	0.36	2.40	1.39

The non-targeted catch and effort by gillnets are presented in Fig 13. Catches by gillnets were relatively low before 1990. After the moratorium, both catch and effort have risen dramatically with the catch peaking in 1999 (10,472 kg) and effort peaking in 1998 (5,862 netdays). There have been slight reductions in non-targeted effort in 1999 and 2000 whilst the targeted effort by gillnet has continued to increase, which accounts for 28% and 47% of the total annual gillnet effort in 1999 and 2000, respectively.

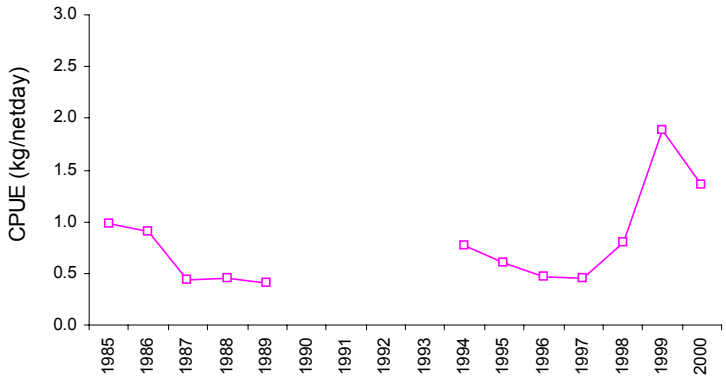
Fig 13. Non- targeted catch and effort for Murray cod by gillnets 1985 to 2000.



Before the moratorium, non-targeted CPUE for the gillnet sector declined from about 1.0 to 0.4 kg/netday (Fig 14). Then the catch rate increased to 0.8 kg/netday in 1994. Although there was a slight decrease from 1994 to 1997, the CPUE dramatically increased to its highest levels in 1999 and 2000 (averaged 1.6 kg/ netday). Whereas the CPUE for the drum net fishery steadily increased from 1997 to 2000, CPUE in the gillnet fishery dramatically increased in 1999, and then dropped slightly in 2000. The peak in CPUE in 1999 may have been due to the highly selective nature of the gillnet fishery. This will be further discussed later.

About 90% of the catch and 97% of the effort in the set line sector have been targeting Murray cod. However, the targeted catch and effort can only be provided for 1985, 1986, 1987, 1988, 1994, and 1995 for confidentiality reasons. After 1985, targeted catch and effort increased significantly to peak in 1987 before declining to about a third in the following year (Fig 15). The catch and effort were at very low levels in 1994 and 1995 following the lifting of the moratorium.

Fig 14. Non-targeted CPUE for Murray cod by gillnets 1985 to 2000.



As with the drum net and gillnet fisheries, the targeted catch rate by set lines dropped before 1990. After the moratorium, CPUE appears to have recovered in the early years (1994 and 1995) (Fig 16). The relationships between catch, effort, CPUE by set lines and river flow are further discussed for the River Fishery in Section 3.2.2. *Regional catch and effort*.

Fig 15. Targeted catch and effort for Murray cod by set lines in SA 1985 to 2000.

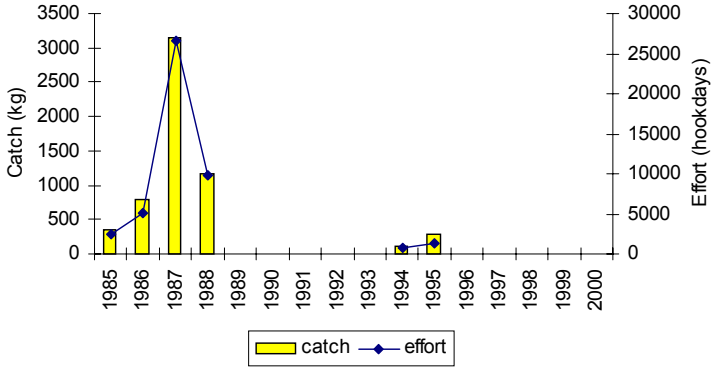
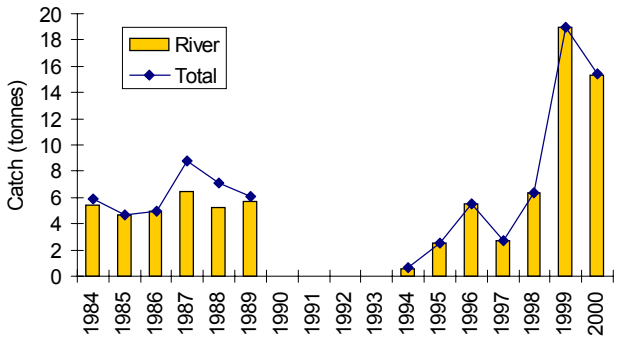


Fig 16. Targeted CPUE for Murray cod by set lines in SA 1985 to 1995 (data from 1996 to 2000 not available due to confidentiality).

3.2.2. Regional catch and effort

Murray cod commercial fishery is mainly a River Fishery in South Australia (Fig 17). More than 90% of the State catch has been from the River since 1984 with the exception of 1987 and 1988, which were relative drought years with 27% of the cod taken from the lakes. Anecdotal information exists suggesting that Murray cod may use the lakes as refuge under drought conditions (Pierce, personal communications). Detailed catches from the lakes are not presented for 1986, 1989, 1994, 1995, 1998, and 2000 due to confidentiality. In the past five years, all of the landings have been taken from the River. Therefore, further results will focus on the River Fishery.

Fig 17. Murray cod State commercial landings and catches from the River in SA 1984 to 2000.



River Fishery

3.2.2.1. Drum net

3.2.2.1.1. Catch, effort, and CPUE

The Murray cod River Fishery is mainly a result of landings from drum nets, gillnets and set lines, which have accounted for 44, 47, and 9%, respectively, of the total River catch since 1985. Drum net catches of Murray cod are all from the river system. Therefore, the State catch, effort and CPUE for drum net sector (Figs 9, 10, 11 and 12) are the same for the River drum net fishery. The non-targeted catch rate in the drum net sector declined during 1985 to 1989, but has increased steadily since 1997 to 0.40 kg/netday in 2000 (Fig 12). The commercial non-targeted CPUE by drum nets will be further discussed in conjunction with river flows in Section 3.2.2.4. *Flow corrected CPUE*.

3.2.2.1.2. Seasonality of catch, effort and CPUE

Average non-targeted drum net effort in the River increases dramatically from a low (294 netdays) in January to a peak (3,926 netdays) in August (Fig 18). Monthly catch closely tracks the effort, which also reaches a maximum in August (1,302 kg). More than half (64%) of the non-targeted drum net catch is taken in July and August. Catch in December (averaging from 1985 to 1989) is below the monthly average level.

Non-targeted catch rate by drum net increases steadily from March to December (Fig 19) although the December CPUE is only an average between 1985 and 1989 and the

CPUE's were generally higher in those years before the moratorium (Fig 12). The relatively high CPUE in December (averaging from 1985 to 1989) despite of the dropped flow is probably due to the increased vulnerability to the post spawning fish that migrating downstream home. The seasonal closure in December after the moratorium should help in protecting these migrating fish.

The catch, effort, and CPUE all appear to relate linearly to river flow in each month (Figs 20 and 21). It is apparent that fishers set more drum nets when flows are high, and that river flow has a positive impact on the catchability of Murray cod in drum net through the spawning migration over the high flow season and over the season when drum nets work most efficiently.

Fig 18. Seasonality of non-targeted catch and effort for Murray cod by drum nets in the River Fishery, SA 1985 to 2000 (1985 to 1989 for December).

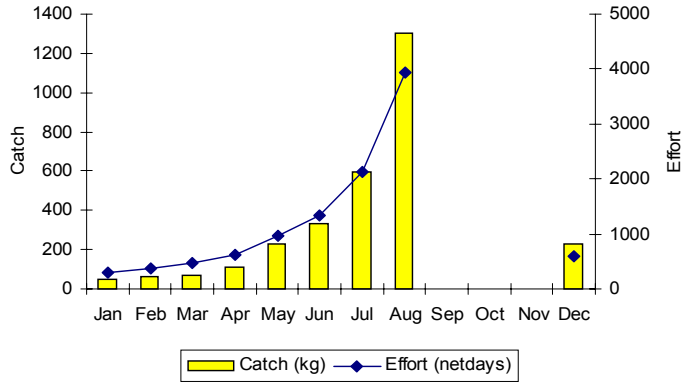


Fig 19. Seasonality of non-targeted CPUE for Murray cod by drum nets in the River Fishery, SA 1985 to 2000 (1985 to 1989 for December).

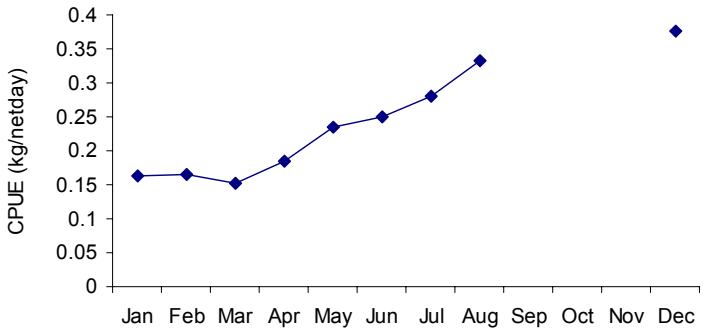


Fig 20. The relationship between monthly average flow and non-targeted CPUE by drum nets from January to August in the River Fishery, SA 1985 to 2000.

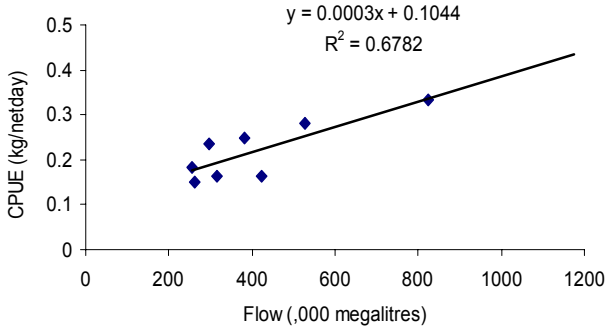
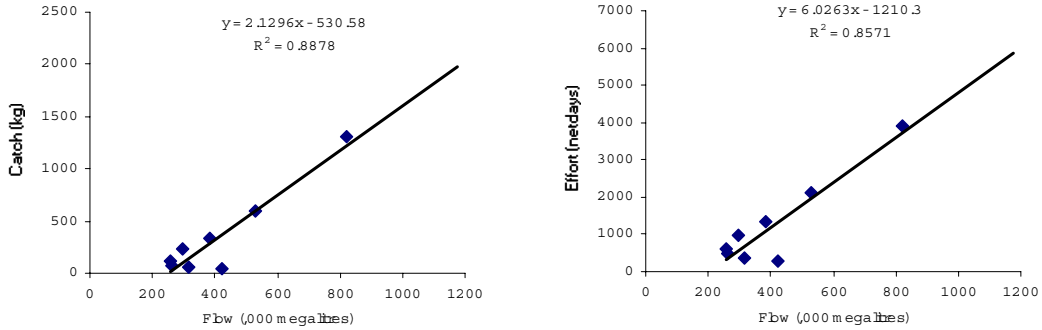


Fig 21. The relationship between monthly average flow and non-targeted catch and effort by drum nets from January to August in the River Fishery, SA 1985 to 2000.

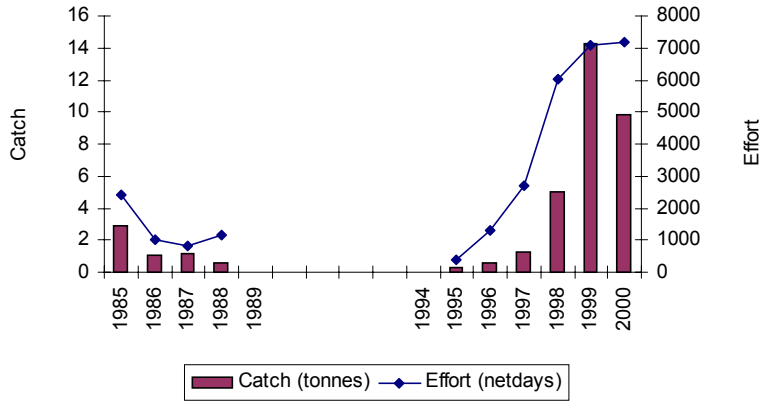


3.2.2.2. Gillnet

3.2.2.2.1. <u>Catch, effort, and CPUE</u>

Gillnet catches from the River were relatively low before the moratorium, remaining below 3 tonnes per annum and declining (Fig 22). Effort averaged 986 netdays for the River in 1987 and 1988, when there were more than five times the effort existed in the Lakes. Before 1990, Lake catch had accounted for about 37% of the State gillnet landings whilst after 1993 almost all production has been from the River. Since 1995, both catch and effort have increased dramatically to a peak in 1999 with 14.2 tonnes and 7,105 netdays, respectively. In 2000, the effort remained about the same but catch has dropped to 9.8 tonnes in the gillnet fishery. Gillnet catch and effort are not reported for 1989 and 1994 as this is confidential as there were less than five fishers active within this gear type.

Fig 22. Total catch and effort by gillnets for Murray cod in the River Fishery, SA 1985 to 2000.



The proportion of targeted and non-targeted catch by gillnets varies from year to year. The percentage of targeted catch ranges from 0 to 52% (mean 25%). However, the trends of targeted catch and effort are not presented because information for most of the years cannot be provided due to confidentiality. The figures for the gillnet targeted fishery in 1986, 1999, and 2000 (Table 3) are also the results for the River fishery in the respective years because the gillnet effort only occurred in the River system in those years. There has been a dramatic increase in targeted effort by gillnets to 1,566 and 2,314 in 1999 and 2000, respectively, with a similar increase of targeted CPUE to 2.4 and 1.4 kg/netday, respectively.

The non-targeted gillnet catch and effort was very low before the moratorium (Fig 23), with landings less than 1.4 tonnes per annum. After 1994, both catch and effort have risen greatly. The effort peaked in 1998 with 5,812 netdays. Although it had reduced slightly in 1999 the catch had more than doubled in this year with a peak of 10.5 tonnes. The dramatic increase in cod landing in 1999 is attributed to the increase in non-targeted catch rate (Fig 24). In 2000, the catch has reduced 37% to 6.6 tonnes with a drop in both effort and CPUE. However, the catch rates in the past two years have been the two highest figures since the re-opening of the fishery in 1994. The peak in catch rate in 1999 may indicate that a strong size class has become vulnerable to the gillnet mesh size in this year. Non-targeted CPUE by gillnets will be further evaluated in conjunction with river flows in Section 3.2.2.4. *Flow corrected CPUE*.

Fig 23. Non-targeted catch and effort for Murray cod by gillnets in the River Fishery, SA 1985 to 2000.

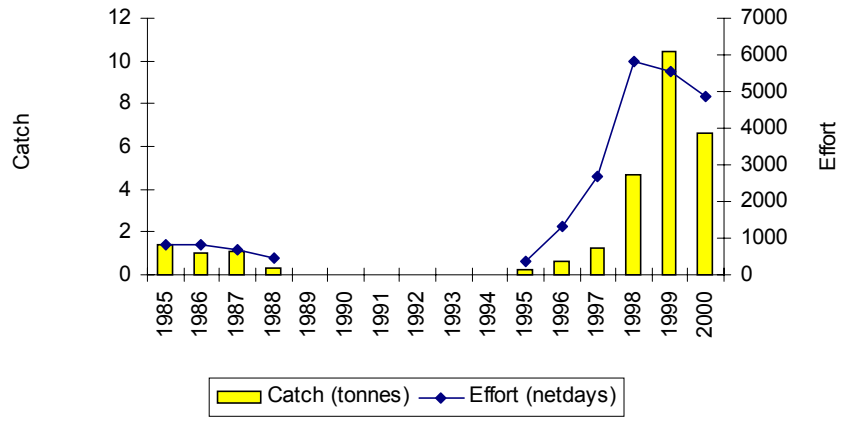
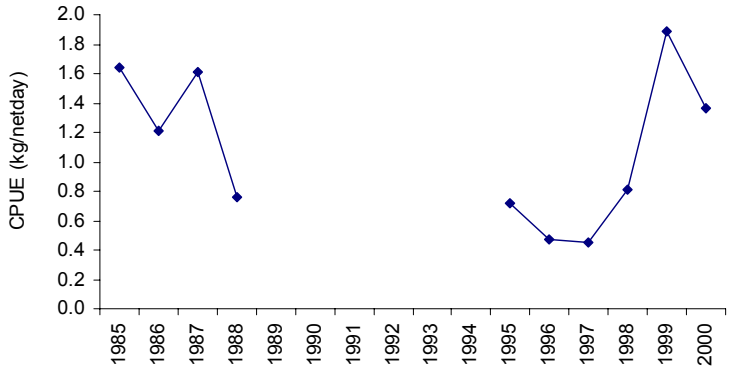


Fig 24. Non-targeted CPUE for Murray cod by gillnets in the River 1985 to 2000.



3.2.2.2.2. Seasonality of catch, effort and CPUE

The monthly non-targeted effort by gillnets increases from a low (188 netdays) in March to the peak (505 netdays) in August (Fig 25). The catch broadly follows the pattern. Respective catch and effort in December cannot be provided because there were less than five fishers active during the month between 1985 and 1989.

Non-targeted CPUE by gillnets remains stable ranging from 0.8 to 0.9 kg/netday between February and May, thereafter the catch rate increases steadily in the following three months (Fig 26). The CPUE peaked in August with 1.7 kg/netday.

Both non-targeted catch and CPUE are closely linearly related to the river flow in the gillnet sector (Figs 27 and 28). However the gillnet effort mostly occurred during low flow years when they are most effective. The peak CPUE in August is probably related to the spawning migration when river flow is relatively high. Nevertheless, the relationships may still indicate that during low flow year/season, relatively high flow would increase catchability of cod in gillnets through the positive effect on fish movement. The linear relationship between gillnet effort and flow is primarily enforced by the high fishing effort in August (Fig 28).

Fig 25. Seasonality of non-targeted catch and effort for Murray cod by gillnets in the River Fishery, SA 1985 to 2000.

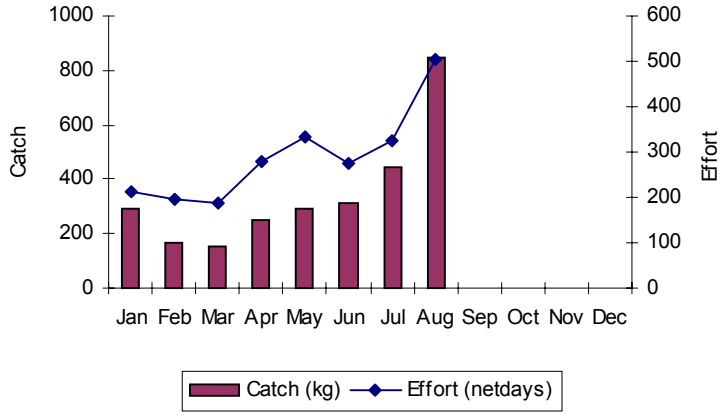


Fig 26. Seasonality of non-targeted CPUE for Murray cod by gillnets in the River Fishery, SA 1985 to 2000.

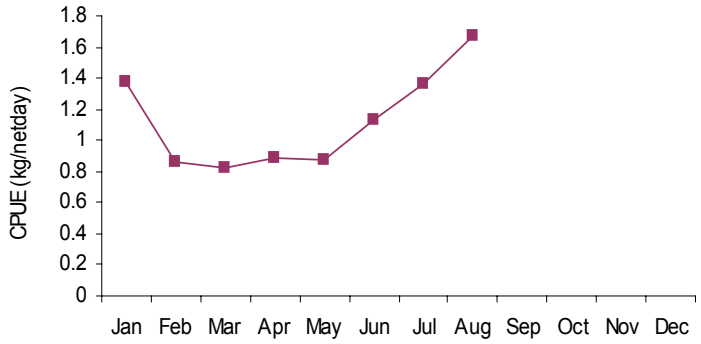


Fig 27. The relationship between monthly average flow and non-targeted CPUE by gillnets from January to August in the River Fishery, SA 1985 to 2000.

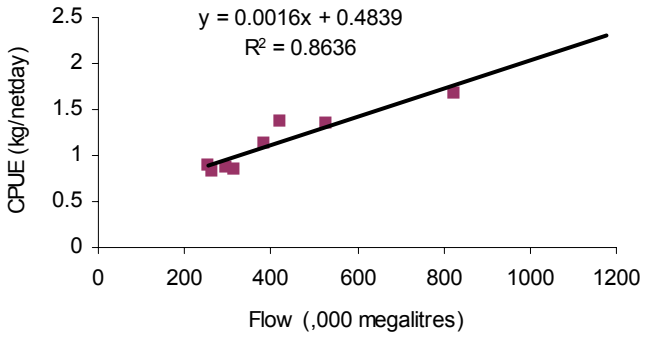
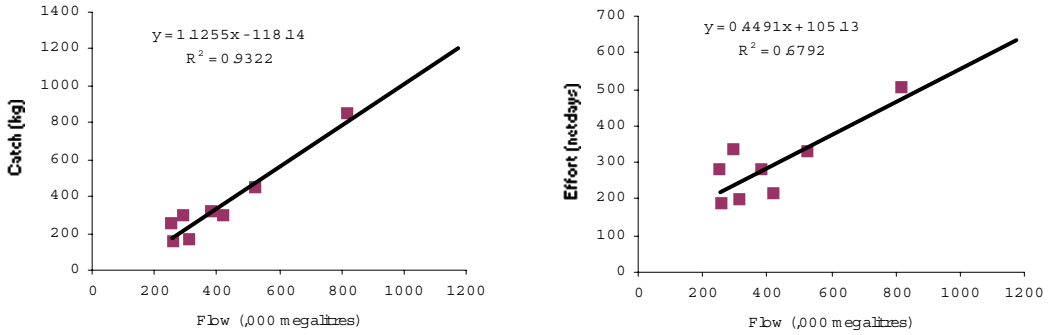


Fig 28. The relationship between monthly average flow and non-targeted catch and effort by gillnets from January to August in the River Fishery, SA 1985 to 2000.



3.2.2.3. Set line

3.2.2.3.1. <u>Catch, effort, and CPUE</u>

As with drum net fishing, the majority of set line activities are within the River. Very minor set line catches were taken from the Lakes in 1987. Therefore, the State information on the set line fishery (Figs 9, 10, 15 and 16) is virtually for the River system. Set line catch and effort are mostly (90%) targeted for Murray cod. There was considerable catch and effort in the River before 1994. The targeted catch and effort peaked in 1987 with 3.0 tonnes and 26,426 hookdays (Fig 29).

The targeted CPUE declined between 1986 and 1987 and remained low in 1988, but increased after the moratorium in 1995 (Fig 30). Due to confidentiality arrangements, detailed targeted catch and effort by set lines cannot be provided for many years (1989, 1996, 1997, 1998, 1999, and 2000).

Fig 29. Targeted catch and effort for Murray cod by set lines in the River Fishery, SA 1985 to 1995 (data from1996 to 2000 not available due to confidentiality).

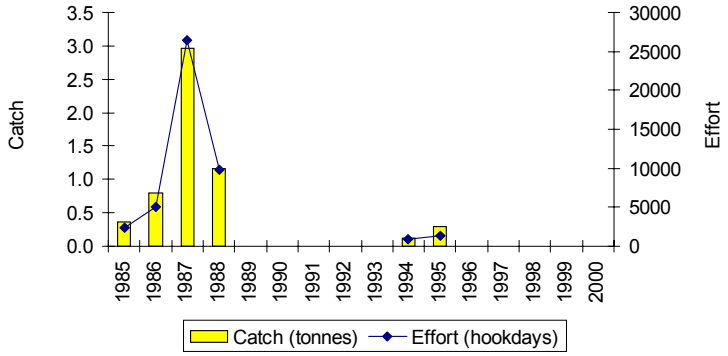
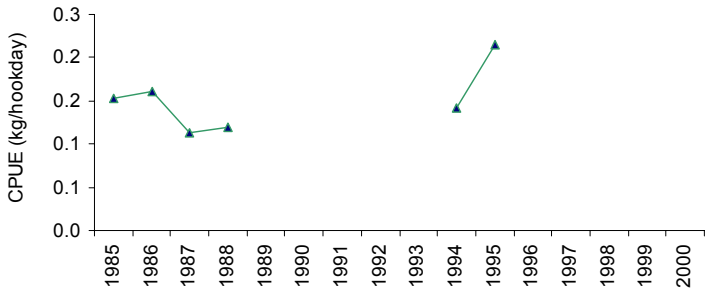


Fig 30. Targeted CPUE for Murray cod by set lines in the River Fishery, SA 1985 to 1995 (data from 1996 to 2000 not available due to confidentiality).



3.2.2.3.2. Seasonality of catch, effort, and CPUE

Seasonal patterns of targeted catch and effort by set lines differ greatly from those by drum nets and gillnets (Fig 31). Most of the set line catches were taken during April and May, the low flow season. There is a trough in both catch and effort in August.

The high catch rates generally occur in May and June (Fig 32), as cod feed up from mid- to late autumn before spawning migration and set lines are baited. An extremely high average CPUE in July, 1.2 kg/hookday, is probably due to the minimal effort (28 hookdays), and may not be representative. Therefore, it is not presented in Fig 32.

As the set line fishery occurs mainly during the low flow season, both average monthly catch and effort by set lines are negatively related to the river flows (Fig 33).

Also there is no significant relationship between monthly targeted CPUE by set lines and river flow. This suggests either that river flow has no direct impact on the catchability of set lines or that other environmental factors (eg. feeding behaviour, turbidity, habitat structure, etc.) confound catch rates by this method.

Fig 31. Seasonality of targeted catch and effort for Murray cod by set lines in the River Fishery, SA 1985 to 2000 (1985 to 1989 for December)

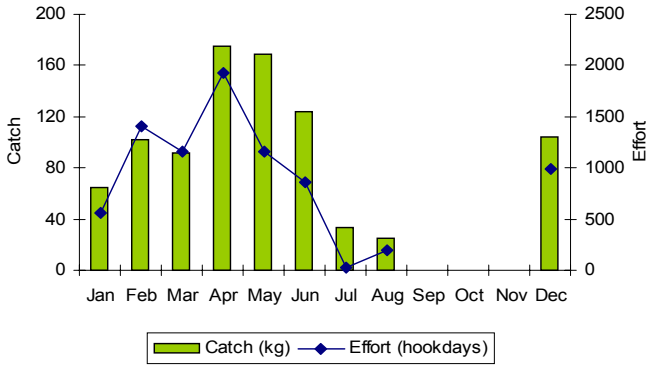


Fig 32. Seasonality of targeted CPUE for Murray cod by set lines in the River Fishery, SA 1985 to 2000 (1985 to 1989 for December).

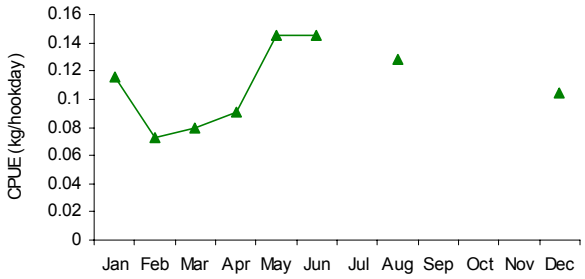
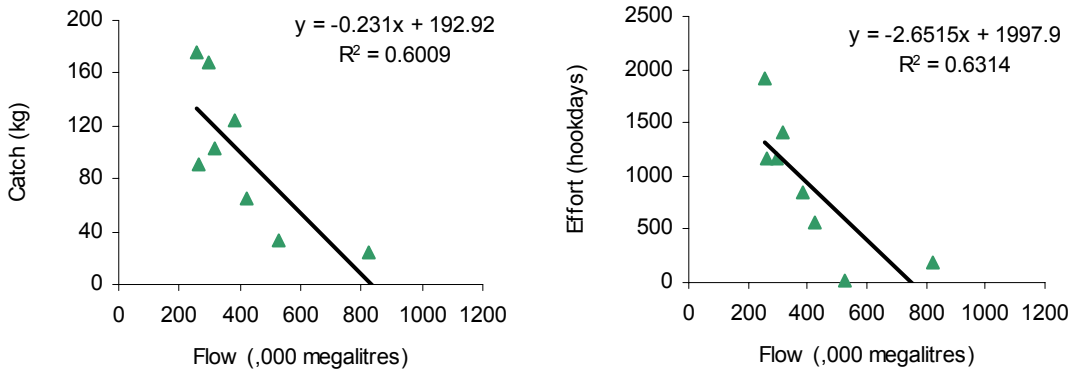


Fig 33. The relationship between monthly average flow and targeted catch and effort by set lines from January to August in the River Fishery, SA 1985 to 2000.



3.2.2.4. Flow corrected CPUE (CPUEFC)

The catchability of Murray cod in both drum nets and gillnets are directly influenced by the river flow with positive linear relationships (Figs 20 and 27). Adjusting CPUE for flow rate allows a more meaningful biological indicator of stock abundance to be calculated. A preliminary index - flow corrected CPUE (CPUEFC) has been derived to account for the influence of flow rate on catch rates. The CPUEFC is basically the commercial CPUE standardised by the volume of flow in 1 teralitre. As the flow information for 2000 is not yet available for the full year, flow corrected CPUE is calculated up to 1999 from the following equation.

CPUEFC = CPUE/teralitre flow *(Equation 1)*

The River Murray is by nature a massively variable system ranging from seven years of droughts to sequential flooding. Fish populations have historically tracked these conditions in their stock abundance (Reynolds 1976, Walker and Thoms 1993). Consequently, the trends of the CPUEFC are further discussed by gear type for the River Fisheries in conjunction with flow conditions.

Non-targeted CPUEFC appeared to decline substantially in both the drum net and gillnet sectors from 1985 to 1989 (Figs 34 and 35). As floods are the critical trigger influencing the spawning success of Murray cod (Rohan 1987, Pierce 1994), the

decline in abundance was probably due to the fact that there had been protracted periods without significant flood events within the River Murray (Walker and Thoms 1993). However, in between, there was a small pulse of relatively high CPUEFC in 1987. This may be due to good spawning three years previously in 1984, a relatively high flow year (Fig 36). According to the age and growth studies in NSW and Victoria (Rowland 1985, Anderson *et al.* 1992), Murray cod take about three to four years to reach current minimum legal size (500 mm), and can remain in the fishery for about another 17 years before being protected by the maximum legal size limit (1100 mm, approximately 21 years of age). With the lower minimum size limit of 460 mm occurring during 1980's, a three-year lag between the 1984 flood and the high CPUEFC in 1987 is possible.

After the moratorium, there was a steady increase in CPUEFC by drum nets, and a more abrupt rise in CPUEFC from the gillnet sector since 1996. The CPUECF peaks in 1999 for both sectors. The increase in stock abundance is attributed to the strong recruitment in Murray cod associated with the floods began in 1989 and proceeded through to 1993 (Fig 36). The regular floods since 1989 have helped the stocks to increase in size. An abrupt rise in CPUECF by gillnet in 1999 (Fig 35) may suggest a possible good recruitment corresponding to the flood of 1996. Nevertheless, it is more likely that the gillnets have meshed a strong size class, as the drastic increase in CPUEFC was not evident in the drum net sector in this year (Fig 34).

The quantitative relationship between the inter-annual stock abundance and river flow cannot easily be determined. Some floods occurred without there being a corresponding peak in catch rate (Figs 34, 35, and 36) or commercial catch for Murray cod (Reynolds 1976). Equally obviously, there are many factors other than flow (eg. water quality, temperature, gear interference, stock size, stock size composition) that can influence the catchability of Murray cod.

Fig 34. Non-targeted CPUE and flow corrected CPUE for Murray cod by drum nets in the River fishery, SA 1985 to 2000.

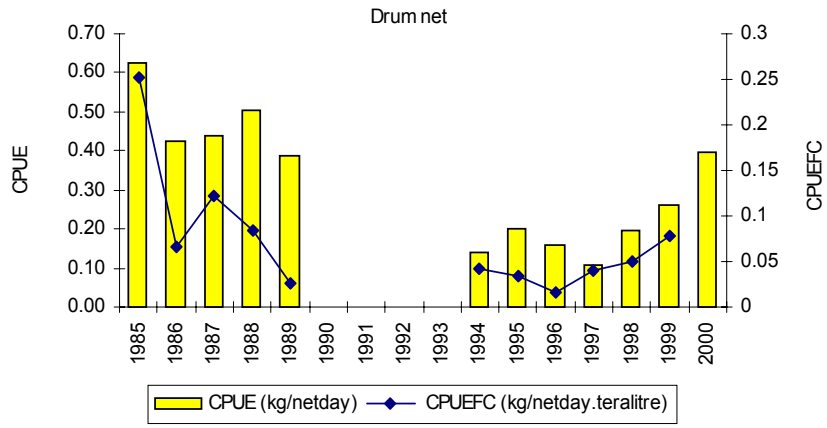


Fig 35. Non-targeted CPUE and flow corrected CPUE for Murray cod by gillnets in the River fishery, SA 1985 to 2000.

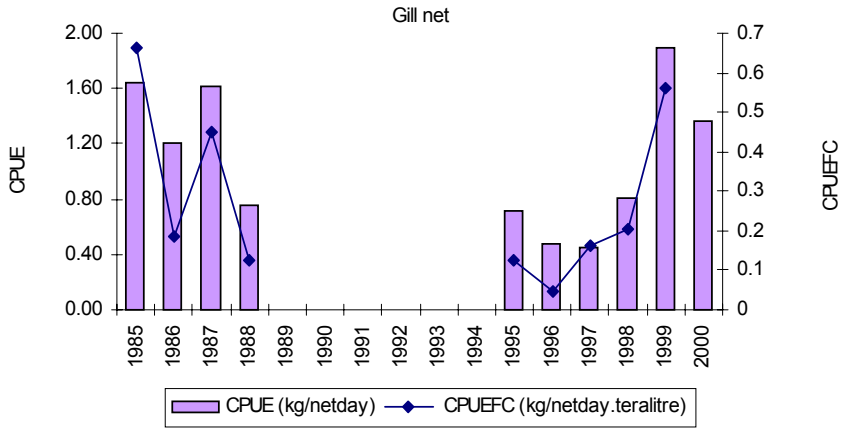
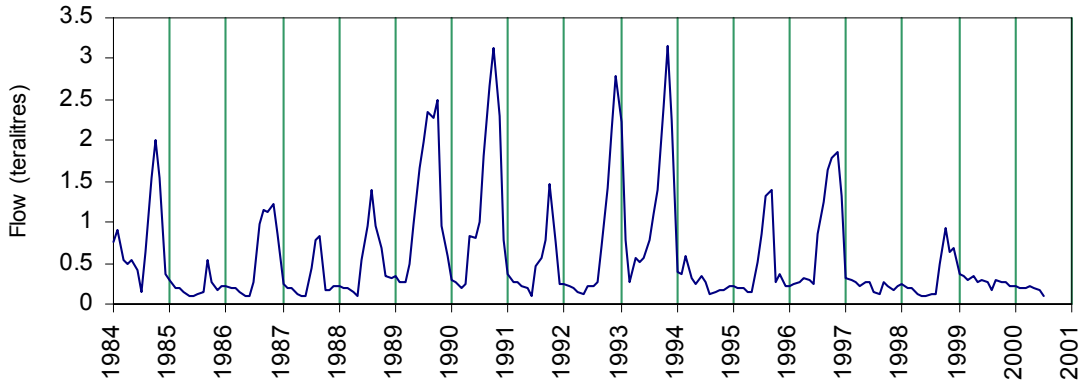


Fig 36. The monthly flow to South Australia at the border from January 1984 to July 2000 (source of data: SA Water).



3.2.3. Summary

3.2.3.1. State fisheries

In general, the State landings of Murray cod have increased since the end of the moratorium on Murray cod fishing in 1994. The annual catches were 19.0 and 15.4 tonnes in 1999 and 2000, respectively.

The catch continues to be dominated by drum net, gillnet, and set line landings (about 98% total catch). Most of the effort by the first two gear types has been non-targeted whilst 97% of the set line effort has been targeting cod. There has been a decline in catch and effort by set lines in recent years.

Drum net catch did not differ greatly before and after the moratorium. The catch and effort increased from 1985 to 1989 whilst there have been large fluctuations with an average catch of 2.8 tonnes since 1994.

Gillnet landings were lower (averaging 1.8 tonnes) before the moratorium. Both the catch and effort has increased dramatically since 1994, particularly in the last three years, when gillnets have become the dominant method instead of drum nets in terms of catch. The catch peaked at 14.2 tonnes in 1999, however it dropped by 31% to 9.9 tonnes in 2000.

Set line catch accounts for 9% of the total landings. Most of the catch and effort occurred before the moratorium with an average catch of 1.1 tonnes.

The CPUE in all above sectors (non-targeted by drum net and gillnet, and targeted by set line) had a general trend of decrease before the moratorium, and since 1994 the catch rates for drum and gillnets have recovered and increased noticeably since 1997 and peaked in the last two years.

3.2.3.2. River Fishery

The Murray cod fishery is basically a River Fishery in South Australia with an average of 94% of the total catch from the River Murray since 1985. Catches from the Lakes only made up a significant production in the drought years (such as 1987, 1988, and 1994) when catches from the River were low.

Drum net catches for Murray cod are all from the river system, as are set line landings, except for 1987, when a minor catch (6% of set line catch) was taken from the Lakes. Although the Lake production had accounted for 62% of the total landings by gillnets in 1987 and 1988, most of the gillnet catch has been harvested from the River, particularly since 1996.

Drum net and gillnet fisheries are strongly seasonal and flow dependent with catch and effort peaking in August. In contrast, set line fishery is most active in "dry" April in terms of both catch and effort.

In order to indicate the stock abundance, CPUE by drum net and gillnet are standardised by flow volume to take into account the bias due to flow dependent catchability. The flow corrected CPUE from both gear types show a general trend of decline between 1985 and 1989. After the fishery reopened, the CPUEFC has increased significantly since 1996, which indicates the high probability of strong recruitment of Murray cod associated with the spring flows in 1989 and the early 1990's that has helped the stock to increase in size from its relatively low state in the late 1980's.

3.3. Other Monitoring

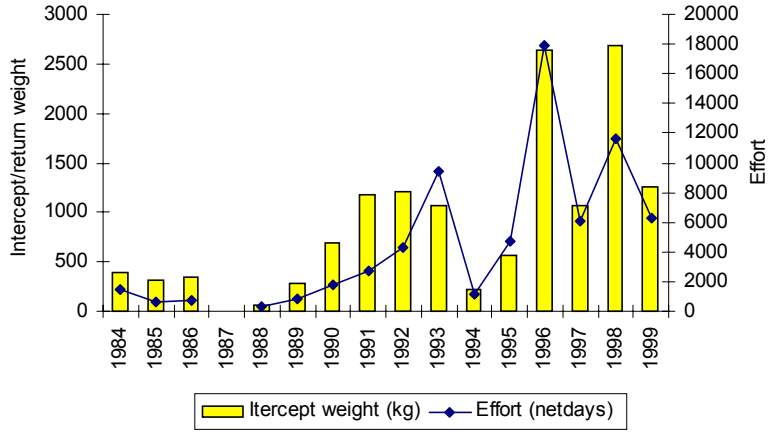
3.3.1. Intercept/return from drum nets

As the Murray cod fishery is closed from September to December inclusive in South Australian waters, the commercial CPUE may not be a good estimate of stock status outside of the protracted closed season for this species. During the closed season, Murray cod migrate upriver to reproduce (Pierce and Doonan 1999). It has been

suggested that the intercept/return rates of cod from drum nets are a useful indicator of abundance when corrected for flow (Pierce and Doonan 1999). Some voluntary commercial data have been collected during the seasonal closure and the moratorium. Information from twenty commercial fishers who have had relatively more consistent records are included to provide the intercept/return index for this species. Only data between September and November are used in order to demonstrate the long-term trends.

The intercept/return weight of Murray cod from drum nets had generally been low (less than 400 kg per season) before the moratorium (Fig 37). The weight increased to more than double during the moratorium (1990 to 1993 inclusive) with an average of 1,032 kg returned between September and November. Drum net effort also rose gradually during this period to 9,460 netdays in 1993. Since 1994, the return weight has fluctuated widely with effort.

Fig 37. The intercept/return weight of Murray cod and effort by drum nets during September and November in SA 1984 to 1999.



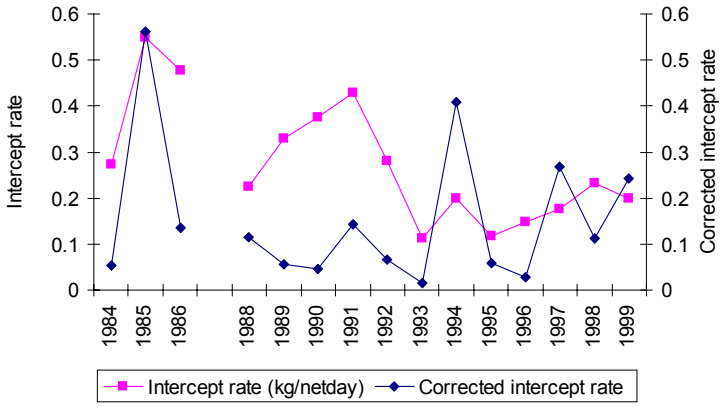
The intercept/return rates of Murray cod from drum nets had increased steadily from 1988 to a peak (0.43 kg/netday) in 1991, then declined drastically in the following two years to 0.11 kg/netday (Fig 38). The high intercept rates in 1989, 1990, and 1991 may be more attributed to river flows, which had triggered the spawning migration and increased the catchability. The intercept/return rate has recovered progressively since 1995 to 0.23 kg/netday in 1998 although there was a slight reduction in 1999 to 0.20 kg/netday.

The intercept/return rates are then standardised by the average flow volume between September and November (*Equation 1*) based on the same assumption that river flow has a direct positive effect on the catchability of drum nets with a linear relationship. The corrected rates are used as an index of the stock abundance.

The flow corrected intercept/return rates of Murray cod from drum nets demonstrate a trend of drastic decline from 1985 to 1990, which remained low during the four year moratorium, averaging 0.07 kg/netday.teralitre (Fig 38). After the moratorium, the index increased dramatically to 0.41 kg/netday.teralitre in 1994, but dropped severely to 0.06 kg/netday.teralitre in 1995. The extreme peak of return rate in 1994 was

probably attributable to a combination of a strong size class of juvenile fish becoming evident and the remaining large fish in the population. This can be demonstrated later from the size composition in 1994. The rates, with some inter-annual variability, have generally risen since 1996. Similar trends have been shown in the flow corrected CPUE in the drum net and gillnet fisheries (Figs 34 and 35). The peaks in drum net intercept rates in 1985, 1994, and 1997 are likely to correspond to previous floods, which induced the spawning success in 1981 (Walker and Thoms 1993), 1990, and 1993, respectively (Fig 36).

Fig 38. The intercept/return rates (kg/netday) of Murray cod and flow corrected intercept/return rates by drum nets during September and November in SA 1984 to 1999.



3.3.2. Size frequency distributions

Information on the length of Murray cod has been collected voluntarily by commercial fishers since 1990. Most of the data were from the intercept/return fish captured during the moratorium and seasonal closure. Fish were generally measured throughout the year before 1994, but with a relatively low sample size. More consistent length data have been provided for the period between September and December since 1995 with a good number of fish being measured. Size frequency distributions are demonstrated in Fig 39. More than 90% of these fish by number were caught in drum nets rather than gillnets. For the year 2000, lengths are only presented up to September.

Temporal trends in size compositions of Murray cod demonstrate a modal progression of distinct size classes (Fig 39). Although with limited sample size, it generally shows that large fish (> 800 mm) had gradually moved out of the fishery from 1990 to 1994. Anecdotal observations indicate that these groups of fish are still present in the population despite the fact that they are not observed as intercepted fish after 1994. This is because, fishers reduced the size of the funnels in their drum nets, and the mesh size of their gillnets, thereby reducing the catchability of fish over the maximum legal size.

In 1993 and 1994, several strong size classes (350-399 mm, and 500-599 mm) had appeared, which probably related to the recruitment success in the previous flood years of 1989, 1990, and 1992.

With more consistent data collection since 1995, there has been a very prominent yearly progression of size frequency modes. The most distinct size class first appears at 350-399 mm in 1995, then progressing to around 450-499, 550-599, and 600-649 mm in 1996, 1997, and 1998, respectively. Based on the age-growth studies in Victoria (Anderson *et al.* 1992), these fish were most likely produced in 1992 and 1993 when major floods came through in the lower River Murray. The modal progression in size composition also explains the relatively high catch rates since 1996/1997 (Figs 34, 35 and 38). A less strong size class, probably from spawning success in 1989 and 1990, has shown a similar growth since 1995, with modes at 550-599, 650-699, and 700-749 mm in 1995, 1996, and 1997, respectively. However, the mode became indistinct in 1998 as the change in size increment between years slows down as fish get older leading to the merging of year classes.

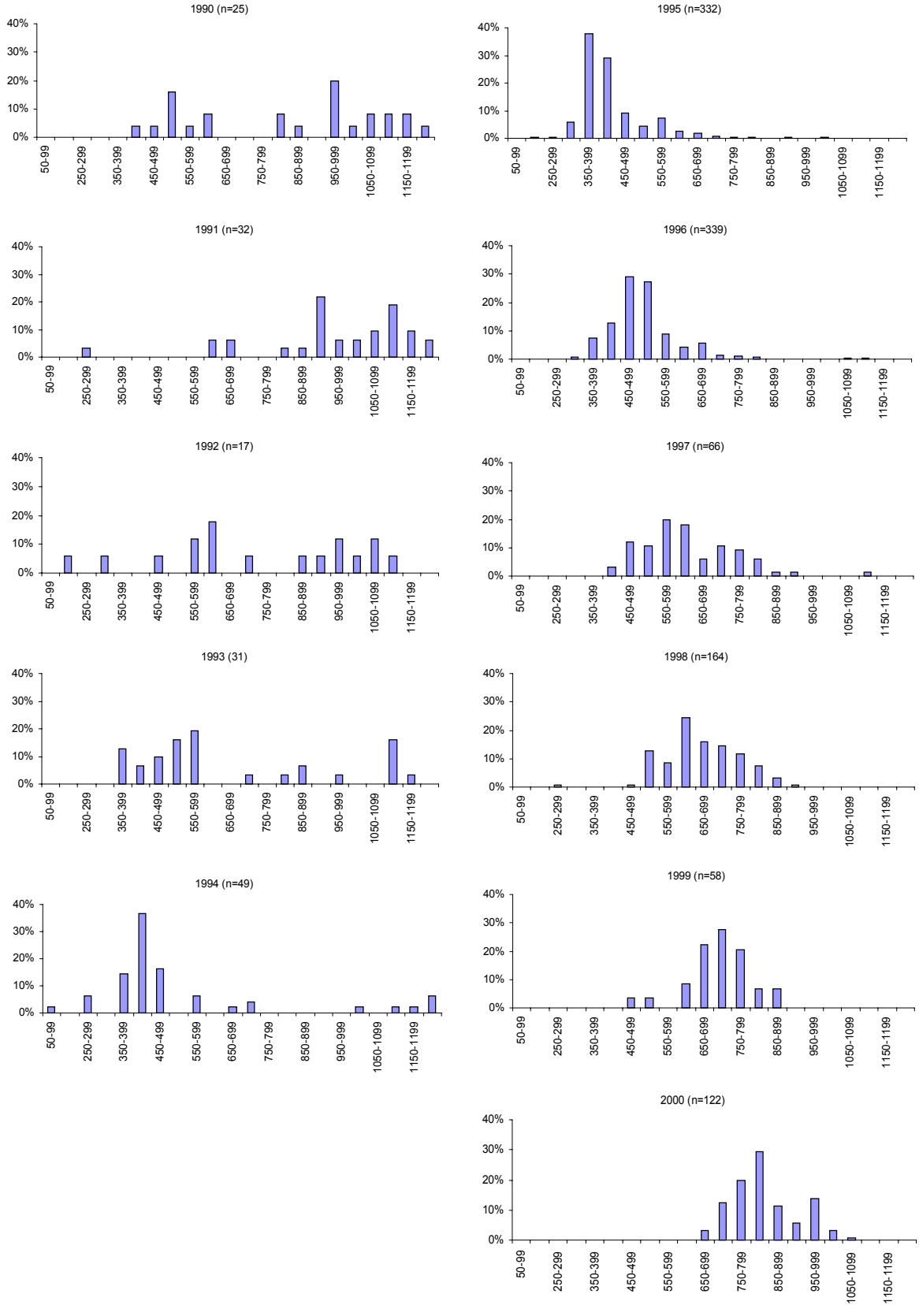
It is noted that a size class between 450 and 550 mm emerged in 1999, which may be a result of recruitment resulting from the high flow in 1996. However it is more likely incidental, as this size class did not appear in 2000. Therefore, the 1996 year class is probably a relatively weak one. This is despite the anecdotal observations of large fish over maximum size limit in 1996, which would have provided adequate spawning potential during the 1996 flood year. It is considered that inadequate water quality associated with the 1996 flow management (Lawrence, personal communications) may have resulted in a relatively weak 1996 year class.

In general, the size frequencies since 1990 demonstrate the recruitment success in the sequential flood years in 1989, 1990, 1992, and 1993, but not 1996. Currently, the Murray cod fishery in SA appears to be dependent on the strong year classes reproduced in 1989 and the early 1990s. Although these fish may remain in the fishery for about another decade, the prospects for the fishery are uncertain unless further strong year classes can be added. The size composition of the fishery shows that there are few distinct new recruits (< 400 mm) since 1997. Thus the fish populations present in the river are primarily the result of recruitment from previous years. This ageing population will continue to be susceptible to gillnet fishing, especially if fishers adjust the mesh size of their gillnets to accommodate the growth of the strong year classes. Added to this is the ongoing risk to stocks of the dramatic increase in vulnerability by recreational fishing during clear water conditions.

As occurred naturally, cod stocks decline in abundance in the absence of flooding, therefore protracted droughts will require increasingly conservative management. The importance of managing spring flows to achieve cod recruitment cannot be overemphasised.

Based on Table 1, it appears that the present minimum size limit of 500 mm is not currently protecting significant reproductive potential for Murray cod. Even if the minimum size limit to be raised to 600 mm, little protection would still occur, until new strong year classes entered the breeding size range.

Fig 39. Length frequency distributions (percent frequency) of Murray cod in South Australia from 1990 to 2000.



4. DISCUSSION

4.1. Reliability of Assessment

4.1.1. Commercial fisheries

As the River Murray is by nature a massively variable system, the fishery also varies strongly from year to year. Using commercial catch and effort can present an approximation of stock abundance and trends. However, there are problems with this approach because of the significant size of the recreational fishery and the unknown but considerable impact of poaching.

The commercial CPUE may not be a good indicator of abundance for this species for many reasons. First, there is a seasonal closure in SA between September and December. Second, the vulnerability of the fish can be strongly influenced by environmental factors such as flow conditions. Murray cod become extremely vulnerable during clear water and high flow. In addition, gear selectivity can significantly bias the catch rate to certain size classes, which may be the case in the gillnet sector.

Furthermore, targeted effort has accounted for only 22% of the total commercial catch since 1985. Also, the assumption that such targeted data from a small number of fishers are indicative of the whole stock throughout SA remains questionable. Due to confidentiality arrangements, trends of CPUE can only be based on non-targeted catch from drum nets and gillnets when fishers are targeting "Callop" (27%) or "ANY" (51%) species. Reporting of unspecified targeting makes interpretation of effort difficult for Murray cod. Appropriate analysis of these data might require further consideration.

The flow corrected CPUE is only a preliminary index for stock abundance. Variations in regressions (Figs 19 and 26) suggest additional factors, besides flow, can affect the catchability, such as turbidity, gear selectivity, etc. Also there is the high inter-annual variability of year class strength. Further research is required before any group of factors can be isolated to appropriately correct CPUE in order to develop a reliable biological performance index for the stock.

As Murray cod is a territorial species, further regional analysis may be required to investigate the stock characteristics within different ecosystems, such as the floodplain and gorge sections of the River. This attempt has not been successful by using commercial data because the numbers of fishers involved are too few leading to patchy information and problem with confidentiality.

4.1.2. Other monitoring

The information on the intercept/return rate of Murray cod during the seasonal closure and the moratorium voluntarily collected by commercial fishers are believed to be useful for an index of recruitment to the fishery. However, more consistent reporting is required. Due to the changes in the gear selectivity by the fishers after the introduction of the maximum size limit, it is at present not possible to provide any

indicator of the size or age composition of the total spawning population and the prospects for monitoring this indicator would be difficult if we were to rely solely on the information collected by commercial fishers. Moreover, the intercept/return rate needs to be corrected by environmental factors, as discussed for the flow corrected CPUE, to develop a relatively unbiased indicator of abundance.

Length data collected by volunteer commercial fishers have been extremely valuable and are highly encouraged for providing some of the biological performance indicators. However, the sample size is small for information prior to 1995. At this stage, there is insufficient information on age of cod in SA, and this has meant the dependence of the age-growth information from populations in NSW and Victoria.

4.2. Management Implications

Commercial catch and effort data suggest that the Murray cod stock in SA has gradually increased after the moratorium. Catches from the river have increased as well as the CPUE. Effort has risen dramatically in the gillnet sector in the last three years. Data collected by volunteer commercial fishers on intercept/return rate of Murray cod from drum nets during the seasonal closure have also demonstrated increased return rates, although with fluctuations. Indications from these data are that current fishing practices and levels are sustainable.

However, size composition data collected by volunteer commercial fishers suggest that the current fishery is mainly dependent on a small number of strong size classes, which correspond to the floods in 1989 and the early 1990's. These fish could remain in both the commercial and recreational fisheries for about another twelve years, and will become increasingly vulnerable if targeted effort increases by both sectors. It is of great concern that there have been protracted periods without significant floods since 1996, with little evidence of pre-recruits in recent years. In addition, the flood in 1996 did not result in a corresponding strong recruitment probably due to inadequate water quality in that year. Therefore, the long-term prospect is uncertain for the fishery unless further strong year classes can be added. Moreover, with the significant size of the recreational fishery and unquantified but considerable impact of illegal fishing, the sustainable harvest status of Murray cod should be classified as "fully exploited". This agrees with the previous assessment of Pierce and Doonan (1999) in which they defined the term "fully exploited" as being for a fishery where "current catches may be sustainable and close to optimum levels; increases in fishing harvest may lead to overfishing".

The current minimum size limit of 500 mm does not appear to be protecting any reproductive potential for Murray cod at present. Even if the minimum size limit is increased to 600 mm, little protection would still occur, until new strong year classes entered the breeding size range.

Dependence on floods for recruitment success indicates the extreme vulnerability of the fishery. Thus flow management to provide regular flooding of adequate water quality is strongly recommended to maximise the chance of breeding success for this species. The retention of the month of December in the seasonal closure is encouraged, as this can further protect returning downstream migrating spawners.

4.3. Future Research and Assessment Needs

There is currently very limited published information on the biology of Murray cod from the South Australian section of the River Murray. As the biological characteristics have been shown to vary considerably between different populations in NSW and Victoria, further research is urgently needed especially in the determination of age, growth, mortality, and reproduction for the South Australian population.

Using commercial data for assessment has its limitations and uncertainties due to the patchiness of information and the questionable assumption that it represents the behaviour of the whole stock of Murray cod throughout SA. Therefore independent research sampling is required to adequately monitor the stock status (including the oversize spawning stock), and ideally this would include relative abundance and age composition of the stock. The use of voluntarily recorded size information from commercial fishers has also proved to be a cost effective method for an independent indicator of status of juveniles and the fished component of the stock, and this and the collection of otoliths for age determination of commercial caught fish should be encouraged.

Murray cod is a territorial species. Reynolds (1983) indicated that Murray cod could maintain their populations without undergoing major upstream spawning migrations; it could be supposed that events such as localised depletion, pollution or destruction of spawning areas by river channelization and desnagging could seriously depress or even destroy these local populations. Independent research monitoring will further facilitate the regional analyses to investigate the stock characteristics within different ecosystems, such as the floodplain and gorge sections of the River, or even at a level of resolution of weir pools.

Also, there are indications that Murray cod can use the lakes as a refuge during drought years. Further work is necessary to investigate the positive impact of this greatly increased drought refuge habitat.

In addition, further research is required to determine if human-induced factors adversely affect the cod population. These include,

- Mortality of undersize and oversize cod caught by commercial gillnets, illegal wire nets, and by recreational fishing.
- Mortality of Murray cod larvae at times of peak irrigation in the summer.
- Migratory barriers – both around Weirs and on/off the floodplain (in particular, through anabranch creeks).
- Predation by exotic fish species (redfin and mosquitofish).

A pre-recruit index is needed for this species to provide the indication of the passage or otherwise of strong year classes before they enter the fishery. Pierce and Doonan (1999) suggested that the number of returned undersize Murray cod in the recreational callop fishery could be a useful pre-recruit index for this species.

As previously discussed, CPUE and intercept/return rates need to be evaluated in conjunction with environmental conditions before indicating the stock abundance.

Further research is required to isolate environmental correcting factors (eg. flow, turbidity, etc). Meanwhile, environmental factors (eg. river flow) can be valuable indicators in stock monitoring as they are directly related to the reproductive success of Murray cod, provided there is an adequate spawning biomass.

In contrast to the commercial fishery, which fishes only 35% of the river system, the recreational fishery has access to the entire inland waters resource in SA. It is necessary to assess the catch and effort in the recreational sector, which has 100% access to the river, as well as the illegal fishery in order to provide a more comprehensive picture of the stock status of Murray cod in SA.

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Appendix I. An example page of South Australian inland waters commercial catch and effort return form.

SOUTH AUSTRALIAN INLAND WATERS CATCH AND EFFORT RETURN

F 103886

Licensee Name: A. FISHER

Licence Number: R 999

Main place of landing: RENMARK (or) Code: R E N

Month: MAY Year: 1986

Fish dealer/Processor sold to
1 SAFCOL AUCTION
2

Number of days on which gear was set (including days when gear was not lifted): 7

ADVANCE NIL RETURNS — Months during which you will not be fishing: SEP. OCT 1986

3. Tick any other methods of disposal
- [x] Personal use
- [ ] Public sale
- [ ] Bait

I certify that the information on this form is complete and correct:
Signature: A Fisher

DAY OF MONTH	MAN DAYS	MAIN AREA	GEAR CODE	* EFFORT	TARGET SPECIES	LANDED CATCH (kg) and CONDITION (Whole, Headed, Gutted)																							
						Species			Species			Species			Species			Species			Species			Species			Species		
						CALLOP			MURRAY COD			CARP			RED FIN			BONY BREAM											
						Code			C A L			C O D			C A R			R F N			B N B								
						Condition	W	H	G	W	H	G	W	H	G	W	H	G	W	H	G	W	H	G	W	H	G	W	H	G	W	H	G
01	1	01	C	17	CALLOP 015		12			5			10																	
02	1	01	C	34	CALLOP 015		18			8			4																	
04	1	01	F	5	ANY 000		10			17			4			1			1											
05	1	01	F	5	COD 020		14			18			7			2														
06	1	01	L	60	COD 020					10																				
12	1	01	C	34	COD 020		7			8			2																	
14	1	01	C	17	ANY 000		6			5			5			1														
							67			71			32			4			1											

*NB. for set gear (i.e., gill nets, drum nets) Effort = No. of nets x No. of days since last lifted.