THE STATUS OF MURRAY COD IN THE MURRAY-DARLING BASIN

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TASKS (AS DEFINED BY ENVIRONMENT AUSTRALIA)

The project involved the following tasks.

a) Provide a brief description of Murray cod in terms of its:
   - Physical attributes;
   - Desired habitat and other environmental conditions;
   - Diet;
   - Reproductive regimen; and
   - Ecological, cultural and economic significance.

b) Collate and present data on current and past (back to 1980 at least) numbers and distribution of Murray cod, using information from a range of sources including:
   - Fishery management agencies (published and unpublished data, field officers/inspectors);
   - Research institutions;
   - Commercial fishing organisations; and
   - Recreational fishing organisations.

c) Provide comment on the rigour of the various sampling and analytical techniques used to generate the information collated in Task b), including a discussion of any viable alternative techniques.

d) Analyse the data collected in Task b) and provide the best possible indication of trends in the number and distribution of Murray cod in the Murray-Darling Basin.

e) Identify and discuss the major threats to the survival of Murray cod, providing where possible, commentary on the relative significance of each threat.

f) Present the current conservation status of Murray cod – using Commonwealth, State, Territory and the Australian Society of Fish Biology listings, and current State and Territory management regimes for Murray cod (eg. seasonal or regional restrictions) and comment on the adequacy of these.

g) Identify the major knowledge and policy impediments to ensuring the sustainable use and management of Murray cod, and recommend ways in which these impediments could be overcome.

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SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The Murray cod is Australia's icon freshwater fish. It is legendary and the mere mention of its name provokes public interest. It has been of unequalled significance to traditional, recreational and commercial fishers and unfortunately, the target for much illegal poaching.

Not only is it the biggest and most highly prized fish in the Murray-Darling Basin but it represents the best indicator species for the ecological status of the Basin as a whole. Its complex life history and the differing requirements of eggs, larvae, juveniles and adults necessitate integration of habitat availability and condition, water quantity and quality and impacts of directed targeting. Managing for Murray cod will equate to managing for ecosystem integrity.

Cod populations have declined dramatically since European settlement to the extent that cod are no longer common in many parts of the Basin. These declines can be attributed to several categories of anthropogenic influence, including habitat degradation, pollution, reduced environmental flows, barriers to migration and fishing.

Persistence of the species (species biodiversity) does not appear to be of immediate concern, but the integrity of wild populations (genetic biodiversity) and of the ecosystems which support them (ecological biodiversity) are seriously threatened.

The benefits of Basin-wide management, or at least complementarity of regional management, are emphasised.

Key knowledge requirements include:

- Better definition of the cultural significance and heritage value of Murray cod, particularly in relation to indigenous people and smaller riparian communities.
- Better indicators of spawning and recruitment success across the Basin.

- More detailed assessment of the hydrological factors which trigger spawning and support successful recruitment.
- Better understanding of the relationships between successful recruitment for cod and for other native species.
- Understanding why some cod populations have failed to recover even though causes of declines appear to have been corrected.
- Better evaluation, assessment and monitoring of genetic integrity of individual cod stocks.
- Assessment of the impact on wild cod populations, and broader aquatic ecosystems, of stocking of cod fingerlings.
- Quantification of the extent of illegal poaching of cod and identification of management strategies, including increased community education, to overcome the problem.
- Evaluation (quantification) of benefits and costs of recreational fisheries to local communities and to cod conservation throughout the Basin.

Suggested policy and management initiatives are:

- There needs to be clearly stated objectives for the management and use of all native fish within the Basin.
- Resource conservation principles and management triggers related to resource sustainability should be given priority over resource allocation issues.
- Management of targeted use, including allocation of Murray cod resources, should be aligned with the assessed impacts of each type of targeting and the costs and benefits of each harvest strategy.
- More effective management (elimination) of illegal traps and nets is required.
- Clearly stated policies and management objectives for recreational fisheries, which promote resource conservation and more equitable sharing of allocations within the recreational sector are required.
- The stocking of hatchery produced fingerlings, particularly into rivers and flood-prone impoundments, requires regulation. Clear objectives, procedures for assessment of anticipated impacts and monitoring protocols are required urgently.

THE STATUS OF MURRAY COD IN THE MURRAY-DARLING BASIN

INTRODUCTION

The Murray cod (*Maccullochella peelii peelii*) (Figure 1) is Australia's icon freshwater fish. It is big, sought after and legendary, with the mere mention of its name creating public interest. However, like many of our native freshwater fish, the Murray cod is fighting a battle for survival, and the decisions of river managers within the Murray-Darling Basin will determine the future of cod in the wild (Koehn, 1994).

Figure 1: The Murray cod (Photo: David Rodgers, from Rowland, 1988)

The Murray-Darling Basin (Figure 2) drains an area of 1.073 million km^2 of south-eastern Australia encompassing parts of Queensland, New South Wales, Victoria and South Australia and all of the Australian Capital Territory. The Murray and Darling Rivers alone comprise approximately 5,300 river km (Humphries *et al*., 1999). The highly variable flow characteristic of this Basin, together with Australia's long isolation from other continents, has played a major role in maintaining a relatively low number of fish species. These species have evolved to take maximum advantage of higher seasonal

flows, which trigger spawning and migration. The Murray cod is the apex aquatic predator in the Basin and the flagship freshwater fish for all of Australia.

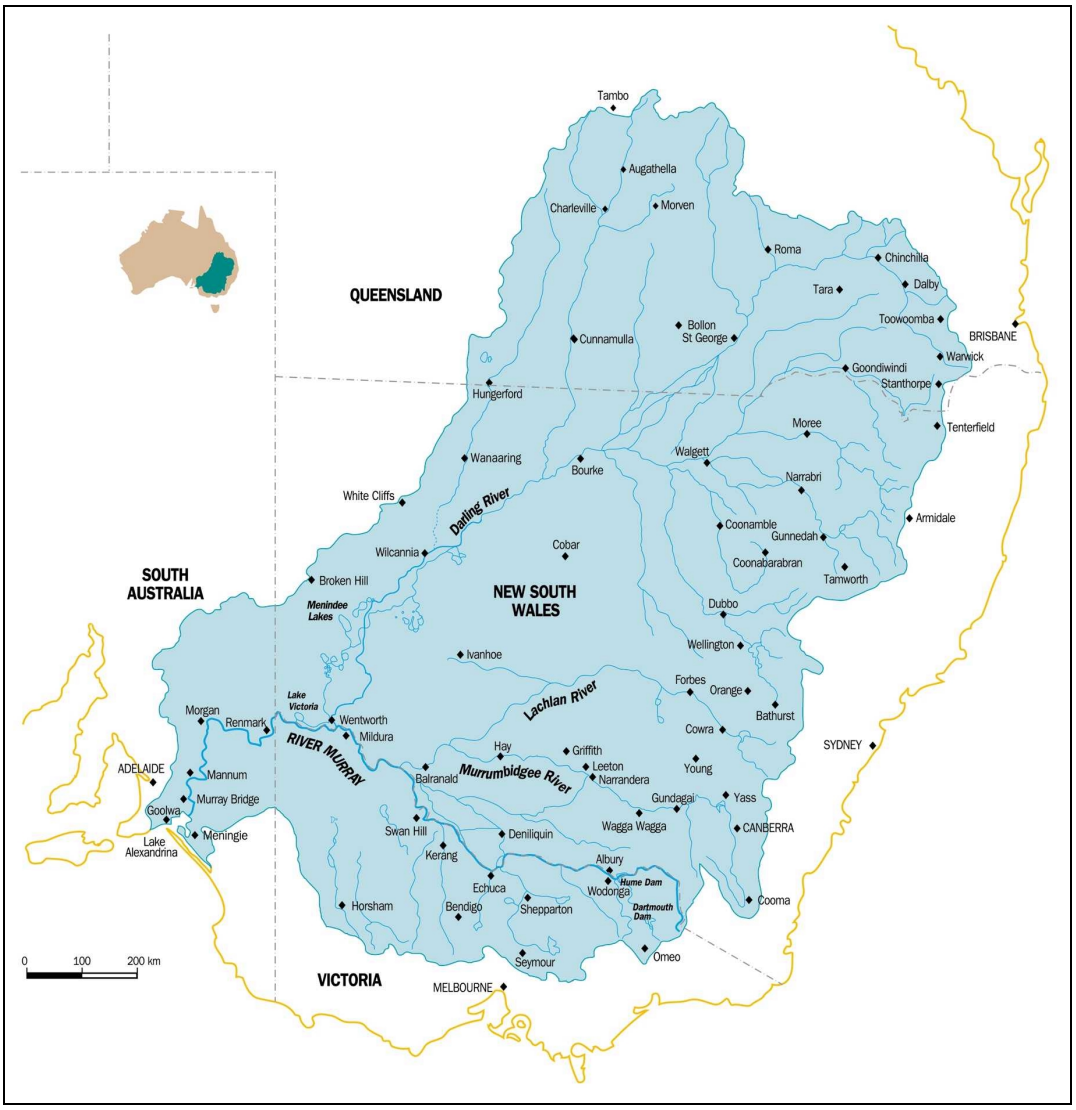


Figure 2: The Murray-Darling Basin.

This report provides a summary of the knowledge of Murray cod stocks and identifies the major knowledge requirements and policy developments likely to underpin sustainable use and management of the species. It draws on the published literature, unpublished reports and consultations with Government, industry and local representatives from throughout the Murray-Darling Basin. The report is structured to deal in turn with the tasks prescribed for this study by Environment Australia – sections are titled accordingly.

A. DESCRIPTION OF MURRAY COD

A.1. Physical attributes of Murray cod

A.1.1. Physical Appearance

Murray cod possess a broad, depressed head with a rounded snout and a concave forehead profile. Their jaws are usually equal in length although occasionally, in very large specimens, the lower jaw protrudes past the upper jaw. The mouth is large and extends beyond the eye, the caudal fin is rounded and 65-81 scales are present in the lateral line. While the body colour varies, the back and upper sides are typically olive-green to yellow-green, the upper flanks mottled brown to pale green, and the belly white (Berra & Weatherley, 1972; Kailola *et al*., 1993; Harris & Rowland, 1996).

A.1.2. Age and Growth

The growth rate of Murray cod varies, though not between sexes, and is thought to be influenced mainly by temperature, type of habitat and food availability (Rowland, 1988).

The general pattern of growth of 1 to 5 year old Murray cod from New South Wales rivers, as reported by Rowland (1988), is shown below:

Age	***1***	***2***	***3***	***4***	***5***
Length (mm)	235	350	500	580	640
Weight (kg)	0.2	0.8	2.0	3.5	5.0

In general, Murray cod older than 5 years grow at a rate of 1.0 to 1.5kg per year in rivers, and 2.0 to 2.5kg per year in large warm water impoundments such as Lake Mulwala, Burrinjuck Dam and Copeton Dam (Rowland, 1988). Murray cod is a relatively long-lived Australian freshwater fish (Kailola *et al*., 1993; Rowland, 1998b). In fact, using the above growth rate trend to determine age, the largest cod ever caught (113.5kg) would have been between 74 and 114 years old (Rowland, 1988).

A.2. Desired habitat and environmental conditions

Murray cod are able to live in a wide range of habitats from clear, rocky streams in the upper western slopes regions of New South Wales to the slow flowing, turbid rivers and billabongs of the western plains (Kailola *et al*., 1993; Rowland, 1988). Generally, they are found in waters up to 5m deep and in sheltered areas with cover from rocks, timber or overhanging banks (Kailola *et al*., 1993; Harris & Rowland, 1996).

In a study of Murray cod in the Ovens River between Wangaratta and Lake Mulwala, cod were radio-tracked to examine movement patterns (Koehn, 1996a). When a fish was located, detailed habitat measurements for parameters such as water depth, water velocity, and quantity and type of wood debris were made at the exact location of the fish and within a 12x12m square surrounding it. This study showed that wood debris was the primary factor determining Murray cod presence. Wood debris in the Ovens River and Lake Mulwala tended to be clumped, with large areas without debris. Therefore, the common occurrence of Murray cod in sites with high densities of wood debris suggests that the selection by Murray cod of sites containing high densities was probably deliberate (Koehn, 1996a). The study concluded:

- Murray cod prefer submerged wood debris as a habitat, with 80% of fish being located within 1m of a snag, and 97% having some form of wood debris within a 12x12m surrounding grid.
- They prefer larger wood debris piles, with 74% of preferred habitats containing more than 50% wood cover.
- They use objects such as wood debris and submerged bank vegetation as shelter from fast-flowing water, and display a tendency to move closer to the river bank to avoid high velocities during high flows.
- They inhabit anabranches and smaller channels as soon as they contain flows, but do not typically move out onto the floodplain.
- They do not show a preference for the deepest areas of the river.

Koehn's study also examined habitat preferences of "young-of-the-year" Murray cod in the River Murray between Lake Mulwala and Cobram. The study determined that the primary factors governing habitat selection, in order of importance were, wood debris, low surface water velocity, close proximity to the bank and shallow water (Koehn, 1996a). These results indicate that habitat preference has similarities between age classes of Murray cod, with 94% of captures of "young-of-the-year" Murray cod being made where wood debris was present (Koehn, 1996a). Depth and flow appear to be key factors in size class preferences.

Murray cod are territorial, with their "territory" usually consisting of a specific hole, snag or area of a river or lake (Kailola *et al*., 1993; Rowland, 1988; Harris & Rowland, 1996). Anglers consistently catch similar-sized cod from the same site or "snag", suggesting that territories are occupied according to the size or aggressiveness of individual cod. The relative quality of the territory is also likely to be important, with the best site being occupied by the largest or most aggressive cod (Rowland, 1988). Evidence of this was shown at the Inland Fisheries Research Station, Narrandera, where it was observed that cod that were placed into earthen ponds at the same time established and maintained territories. These resident cod were often aggressive toward later introductions, in some cases leading to the death of recently introduced cod (Rowland, 1988).

A.3. Diet

The Murray cod is the top predator of our inland rivers. Cod are carnivorous and at times, voracious feeders, eating both invertebrate and vertebrate organisms (Rowland, 1988). Upon hatching, larvae are 5-8mm long and within 8-10 days are able to feed on zooplankton. After reaching a length of 15-20mm, they begin to feed on aquatic insects (Kailola *et al*., 1993). The most common components of adult cod's diet include crustaceans such as yabbies, shrimp and crayfish, and fish such as the introduced common carp, goldfish and redfin perch, and the native fishes bony herring, catfish, golden perch, western carp gudgeon and even other cod (Kailola *et al*., 1993; Rowland, 1988). Less common items to have been found in Murray cod include ducks, cormorants, grebes, tortoises, water dragons, snakes, mice, frogs and mussels (Rowland, 1988).

A.4. Reproductive regime

The Murray cod, like many temperate fishes, has a distinct annual reproductive cycle, which culminates in a relatively short, well-defined breeding season (Rowland, 1998a). Even though Murray cod is one of the most important species in the inland fisheries of south-eastern Australia, it was only recently that quantitative studies of the reproductive biology of Murray cod in the Murray-Darling river system were published. A study on the gonadal development and the reproductive cycle of Murray cod in Lake Charlegrark and adjacent farm dams in western Victoria was published by Gooley *et al*. in 1995. However, these populations were introduced, so aspects of the species biology may have differed from natural populations (Rowland, 1998a).

A.4.1. Spawning

Studies of Murray cod held in earthen ponds have provided some information on the reproductive biology of this species (Rowland, 1998a). However, it is becoming increasingly apparent that reliance on hatchery-based studies as a major source of information is an unsound foundation upon which to base river management, and that a better understanding of how fish interact with, and respond to, their environment is required (Humphries *et al*., 1999). Nevertheless, from earlier studies it appears that Murray cod prefer protected spawning sites, and typically spawn large (3.0-3.5mm diameter) adhesive eggs onto firm substrates such as hollow logs, rocks, pipes and clay banks, from spring to early summer (Cadwallader, 1986; Kailola *et al*., 1993; Rowland, 1998a). It was originally assumed that rising water levels induce spawning, with Lake (1967) demonstrating that a slight "runoff" of water into a pond induced cod to spawn. Since then, studies by Rowland (1983), and Cadwallader and Gooley (1984) have demonstrated that spawning is not dependent on a rise in water level in ponds. Rather, a rise in the temperature of the water, to 16-21°C provides the stimulus for spawning for this species (Cadwallader & Backhouse, 1983; Kailola *et al*., 1993; Rowland, 1988; Rowland, 1998a). Because spawning is temperature dependent, the actual season varies latitudinally (Rowland, 1998a). Murray cod breed in September or early October in the

northern parts of the Darling River and in tributaries such as the Gwydir River, and in late October and November in the Murray, Edward, Wakool and Murrumbidgee Rivers (Rowland, 1988). In these southern tributaries, the breeding season is typically completed by early December. In contrast, spawning may occur later in the colder waters above Burrinjuck and Blowering Dams, Hume Weir, and in some Victorian tributaries (Rowland, 1988).

A.4.2. Movement

Seasonal rises in flow have long been thought to initiate upstream pre-spawning movements in several of the larger Murray-Darling fish species. The hypothesis has been that fishes move upstream in response to increasing flows and then move laterally on to the floodplain to spawn, or that they spawn mid-channel and free embryos are washed downstream to inundated nursery areas (Humphries *et al*., 1999). This upstream movement would both compensate for the downstream drift of embryos and larvae and help prevent larvae from being washed down to unfavourable areas, or even out to sea (Humphries *et al*., 1999).

Early studies of Murray cod concluded that this species was non-migratory (with tagged adults moving less than 10km) and essentially sedentary (Kailola *et al*., 1993; Humphries *et al*., 1999). However, recent studies have demonstrated that Murray cod do in fact, make relatively large upstream movements prior to spawning before making a return journey (Koehn, 1996a; Humphries *et al*., 1999). Koehn (1996a) demonstrated that radio-tracked cod in the Ovens River between Wangaratta and Lake Mulwala were relatively sedentary during summer, autumn and early winter, moving only locally. However, this changed in late winter/early spring, when a major upstream migration began, with upstream movement continuing until late spring. The onset of this migration generally coincided with elevated water levels, although migration occurred in both flood and non-flood years, and appears to be related to pre-spawning activity.

Many of the radio-tagged fish were tracked for two or three successive years and in each year, the same pattern of movement was observed, with many fish following the same route as they had in previous years. Spawning was followed by a rapid downstream migration, with almost all fish returning to exactly the same area they had occupied before their upstream movement. In most cases, cod returned to exactly the same snag, even after travelling distances of up to 240km (Koehn, 1996a).

Studies of life history traits, spawning cues, movement and migration, habitat use and recruitment have provided evidence that traits vary widely among species and may not even be consistent for one species across different regions (Humphries *et al*., 1999). In a comparison of cod movement patterns in the regulated River Murray, and the unregulated Ovens River, Koehn and Nicol (1998) found that movements in both areas were seasonal, and concentrated in the late winter-spring-early summer period. Overall movement was generally upstream, although movements occurred in all directions. The upstream trend continued until after spawning had occurred, and was followed by downstream movements. While the patterns of movement were similar in both rivers, they were more strongly evident in the Ovens River. Movements of Murray cod, in terms of the number of fish moving, the distances travelled and the regularity of movement, were less with lower flows than with higher flows. In general, fish in the regulated River Murray moved less often and not as far as those in the Ovens River (Koehn & Nicol, 1998).

A.4.3. Hatching & Fecundity

At water temperatures of 20-22°C, hatching usually occurs 5-7 days after fertilisation, and a batch of eggs takes 3-4 days to hatch (Kailola *et al*., 1993; Rowland, 1988). At the time of hatching, the larvae are 5-8mm and have a large yolk sac. They remain clumped at the site for 8-10 days until the yolk sac is absorbed. The larvae then disperse and begin feeding (Cadwallader & Backhouse, 1983; Rowland, 1988; Harris & Rowland, 1996).

The fecundity of Murray cod is low relative to the size of the fish (Cadwallader, 1986). Rowland (1998a) demonstrated that in fish sampled from five sites in the Murray-Darling

river system, the number of large (>2mm), yolky oocytes per female ranged from 6,800 (480mm, 2.1kg) to 86,000 (1050mm, 22.7kg). These figures support those reported by Kailola *et al*. (1993), which stated that a female weighing 2.5-3.0kg may produce approximately 10,000 eggs, a 5kg female 14,000-30,000 eggs, and a 23kg female 90,000 eggs. Rowland (1998a) found that absolute fecundity generally increased with increasing length and weight of females, although large variations in fecundity of similar-sized females were observed. In contrast, relative fecundity ranged from 3.2-7.6 eggs/g and, despite a small sample size for females weighing more than 11kg, the data suggested that relative fecundity decreases with increasing size and age in Murray cod (Rowland, 1998a).

A.4.4. Age and Size at Maturity

The age, or size, at maturity in fishes depends on various demographic and environmental factors, including growth rate (Rowland, 1998a). While Murray cod grow at different rates in rivers and impoundments in New South Wales, sexual maturity in individual populations appears to be age-dependent, with many cod mature at 4 years, and all females and most males at 5 years of age (Rowland, 1998a). In contrast, female Murray cod from Lake Charlegrark mature at 6 years of age and a minimum size of 2.0kg, and males at 3-4 years and 0.7kg (Rowland, 1998a). Clearly, there is much diversity in the growth rate and age and size at maturity for Murray cod from different locations. The fact that the size and age measurements taken for cod from the study by Rowland (1998a) do not match the pattern of growth described by Rowland in 1988 (section A.1.2) demonstrates that the relationship between age, size and sexual maturity is not well understood and is more variable than suggested by some studies. In some fish species, slow-growing individuals mature at greater ages and smaller sizes than faster growing individuals. Therefore, the reported variation in age and size at maturity between Murray cod sampled from New South Wales and Victorian waters may be at least partly due to slower growth in the colder, southern waters (Rowland, 1998a).

A.5. Significance of Murray cod

A.5.1. Ecological significance

Fish provide a number of functions in freshwater ecosystems. They occupy trophic levels from herbivores and detritivores through to carnivores at the top of the food chain. Fish prey on other animals and in turn form prey for others, usually more advanced life stages, or larger individuals, of other species. They may even have a role in maintaining water quality through top-down control, as planktivorous fish may graze zooplankton to low levels, which in turn allows phytoplankton to grow and develop algal blooms. If carnivorous fish feed on smaller planktivorous fish and are able to control their numbers, then zooplankton may remain in sufficient densities to prevent algal blooms from developing (Gehrke, 2000).

The interactions that determine food chain processes can be quite complex and are strongly influenced by nutrient availability and environmental conditions. Migratory fish also play a role in transporting carbon and energy upstream in rivers, which partially counteracts the movements of nutrients washed downstream. Consequently, fish play a vital role in maintaining the ecological integrity of aquatic ecosystems (umbrella species). Fish conservation is therefore, a much bigger issue than simply ensuring the survival of species for exploitation by humans – it is an essential component of the well-being of entire river systems on which humans depend (Gehrke, 2000).

Freshwater fish communities in the Murray-Darling Basin are relatively simple, with few species at any one trophic level. This means that if the population of any one species becomes depleted, then there may not be another similar species to take on that ecological role.

Murray cod is the apex fish predator in the Murray-Darling system. It has evolved, together with our freshwater systems, over hundreds of thousands of years to achieve a balance within the total environment. As the foremost predator it is arguably the best

integrator, and hence indicator, of the health of the total ecosystem that supports aquatic life in the Murray-Darling Basin (Harris, 1995).

The possible loss of this socially and ecologically flagship species should not be measured only in terms of the demise of one species. The impacts on all levels of the existing food chain would be expected to be enormous. In addition, increases in the populations of alien fish species, such as carp and tilapia, would be greatly facilitated by the removal of the major natural predator. The ecological significance of the Murray cod on the Murray-Darling system can be argued to be more complex and profound than that for any single terrestrial animal, except humans.

A.5.2. Cultural significance

The Murray cod plays a prominent role in Aboriginal culture. According to Aboriginal legend,

> "the Murray cod burst forth from the depths of the earth at the source of the River Murray, which was then only a small stream of water trickling to the southern ocean. The Murray cod struggled down the narrow stream, digging with its head and swinging its powerful tail, making it wide, forming bends and creating the River Murray. The Great Prophet, Nepelle, and the creative hero, Ngurunderi, then speared the huge cod at the site known as Lake Alexandrina. They cut it into pieces and threw them back into the water, naming them *tarki* (golden perch), *tukkeri* (bony bream), *tinuwarre* (silver perch) and all the other fish of the inland waters. When they had finished, they threw the rest back and said 'You keep on being *ponde* (Murray cod)'."
>
> (Rowland, 1988; Rowland, 1989)

Fish were an important food source for Aboriginal tribes along the Darling and Barwon Rivers (Gehrke & Harris, 2000). Elaborate fish traps were used to catch Murray cod particularly as fresh flows of water moved downstream (Gehrke & Harris, 2000). Presumably, other species such as golden perch, silver perch, freshwater catfish and bony herring were also caught, although only Murray cod is mentioned in historical accounts (Rowland, 1988). The lack of reference to other species emphasises the relative

importance of Murray cod to Aboriginal people living along the Darling River, as well as highlighting the abundance of this species in earlier times (Gehrke & Harris, 2000).

The abundance of fish in the rivers of the Murray-Darling system was recorded in the journals of many explorers and squatters when Europeans first visited the region. The first European reported to see a Murray cod was the explorer George Evans. He gave the name Fish River to the first significant waterway that he came upon west of the Great Dividing Range because "*if you want a fish it is caught immediately; they seem to bite at any time*" (Rowland, 1988; DNRE, unpublished).

Later, in 1831, the holotype of *Maccullochella peeli* was collected from the Peel River by the explorer Major Thomas Mitchell (Rowland, 1988). Members of the expeditions led by John Oxley and Charles Sturt caught and ate Murray cod. Their reports of the tremendously great abundance of the species are shown in Oxley's words during his expedition in 1817. Of Murray cod from the Lachlan River, he wrote:

> "If however the country itself is poor, the river is rich in the most excellent fish, procurable in the utmost abundance. One man in less than an hour caught eighteen fish, one of which was a curiosity from its immense size and the beauty of its colours…..It weighed an entire 70 pounds,……Most of the other fish taken this evening weighed from fifteen to thirty pounds each".
>
> (Rowland, 1988; Faragher & Harris, 1994)

Bennett (1834, cited in Rowland, 1989) wrote that large quantities of the delicious "River cod" weighing up to 120 lbs each were caught in the Yas [sic] and Murrumbidgee Rivers, and in 1836 he recommended to the Acclimatization Society of New South Wales that every endeavour should be made to propagate them. Murray cod were actually held in such high esteem, that Dr. Gunther considered the species worthy of acclimatisation in England (O'Connor, 1897 cited in Rowland, 1989), and Ramel (1868; cited in Rowland, 1989) suggested that Murray cod be introduced in Europe.

Peter Beveridge, who squatted on the Murray near Swan Hill between 1845 and 1868, recorded the fishing success of Aboriginal people:

> "On many occasions I have seen half a ton of fish drawn from the lagoons at single hauls, consisting of cod, perch, catfish, blackfish and turtle….codfish from fifty pounds down to two, and perch from ten pounds down to the same minimum; the large mesh precluding the landing of lesser fish…."
>
> (DNRE, unpublished)

In view of the great abundance of Murray cod at the time of first European settlement, the relative clarity of many of our inland rivers at that time and hence high visibility of cod, the ease of their capture and their excellent edible qualities, it must be assumed Murray cod were of immense importance to Aboriginal people throughout much of the Murray-Darling Basin.

In many areas of Australia the mere mention of Murray cod generates public interest, which is not confined to anglers living near cod-inhabited areas. Because Murray cod are so culturally significant in Australia an important aspect of the management of this species is that they are not just another fish species, but are, in fact, a part of Australian folklore, and a part of our cultural heritage (Koehn, 1994).

A.5.3. Economic significance

There are many aspects to the economic significance of Murray cod. These include value as a key component of the biodiversity and ecology of the Murray-Darling Basin, as an indicator of river and ecosystem health, as a target for, and product of, recreational fisheries and as the basis of commercial fisheries.

Recent commercial cod catches from South Australia and New South Wales combined, returned approximately $800,000 annually to licensed fishers. The total value of these catches to the community (local and otherwise) would be much greater when appropriate

multipliers are incorporated. However, the costs of management of the commercial fisheries were also significant and have not been published.

The aquaculture of Murray cod for consumption as food in New South Wales (Table 1) and Victoria (Table 2) is a rapidly growing industry. It produced approximately 80 tonnes in the last year, valued at approximately $2 million at the first point of sale. The industry's goal for annual production is 5000 tonnes (Gooley, *pers. comm*). The aquaculture industry also produces hundreds of thousands of cod fingerlings for stocking to enhance recreational fisheries.

Table 1: New South Wales Aquaculture Production of Murray cod (from NSW Fisheries).

Year	*Permits*	*Active Producers*	*Tonnes*	*Average Price*	*Value ($)*
1999/00	81	8	8.4	21.39	179,727
1998/99	70	5	10.4	21.01	228,855
1997/98	65	4	1.4	23.23	31,708
1996/97	63	3	0.6	30.20	19,025
1995/96	28	4	0.7	19.30	13,390
1994/95			>0		
1993/94			0		
1992/93			0		

Table 2: Victorian Commercial Aquaculture Production of Murray cod (from Victoria, DNRE)

Year	*Production (tonnes)*
2000/01	70+
1999/00	23
1998/99	2

No assessments of the value of the recreational fishery in the Murray-Darling Basin are available. Worldwide, economists struggle to evaluate recreational fisheries (Pitcher, 1999). Preliminary and unpublished information from the ongoing survey of Australia's total recreational fisheries suggests a total annual catch of Murray cod in the New South Wales portion of the Basin of approximately 220 tonnes, 120 tonnes of which was consumed and 100 tonnes released (calculated from data from Gary Henry, *pers. comm*.,

see Table 3a & b). The value of this kept catch as food would be approximately $2.4 million (at the commercial value of $20 per kg, Table 1) but the value to local communities from the expenditure of anglers is generally assumed to be much higher. Note that for several reasons, total expenditure should not be used to "value" fisheries (Hundloe, 1997); the majority of Australia's expenditure on recreational fishing is on imported gear and equipment and is therefore of questionable "value" (Kearney, 1999a). Published estimates of expenditure by anglers in Australia have been dominated by marine or estuarine activities. It is possible the percentage of expenditure on inland fisheries that is not on imported equipment is much higher. It is also relevant that the relative "value" of tourists fishing an area generally exceeds that of locals (O'Bara 1999, Kearney 1999b). The relative "value" of expenditure on recreational fishing to smaller, inland towns and businesses may well be greater than similar expenditure in larger or coastal communities. If, as it is argued (Kearney, 1999a), the real value of recreational fishing is social and not directly related to expenditure, the true contribution to society could greatly exceed current perceptions of value.

Table 3a: Catches of Murray cod by New South Wales diarists participating in the National Angling Survey (from Henry, *pers. comm*., 2001).

Region Code	*Region Name*	*Number of Cod Kept by Diarists*	*Number of Cod Released by Diarists*	*Raised Estimate of Annual Keep in NSW*	*Raised Estimate of Annual Released*	*Estimated Annual Total Catch in NSW*
1	North West	67	121	26,700	48,500	75,200
2	Darling River	30	23	12,100	9,100	21,200
3	South West	7	90	2,800	36,100	38,900
4	River Murray	9	11	3,500	4,400	7,900
58	ACT	0	2	0	800	800
Total		**113**	**247**	**45,100**	**98,900**	**144,000**

Table 3b: Fishing Effort by New South Wales diarists participating in the National Angling Survey (from Henry, *pers. comm*., 2001).

Region Code	*Region Name*	*Number of Fishing Events by Diarists*	*Estimated Total Annual Number of Fishing Events for NSW*
1	North West	960	384,000
2	Darling River	240	96,000
3	South West	1,160	464,000
4	River Murray	180	72,000
58	ACT	94	37,600

The difficulties of valuing biodiversity and the contribution of even one species to ecosystems are well recognised (see for example Environment Australia, June 2000). Environmental values, social values and monetary expenditures and returns all impact "economic significance".

It is not possible at present to estimate the true economic significance of Murray cod but as the apex predator in the aquatic ecosystem (and an umbrella species), a key indicator of the well-being of the total ecosystem of the Murray-Darling Basin, the pinnacle target for recreational fishers, the highest priced commercial fish, the general community icon (flagship) species and the only freshwater fish known by most Australians, the real economic (and political) significance would be enormous.

B. DATA ON CURRENT AND PAST NUMBERS AND DISTRIBUTION OF MURRAY COD

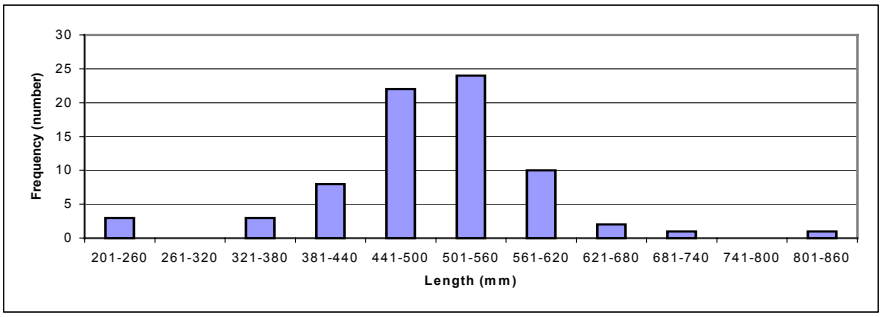
Data on freshwater fish throughout Australia remain the prerogative of individual states and territories. Varying approaches have been taken to the management, monitoring and research of freshwater species and fisheries based on them. Consequently, when compiling and analysing data and information on Murray cod in the Murray-Darling Basin, it is appropriate to start on a state-by-state basis.

B.1. Queensland

The targeted exploitation of Murray cod in Queensland is limited to the recreational fishery; cod have never been taken in a managed commercial fishery. Recreational freshwater fishing in Queensland includes the legal use of up to six set-lines per individual, which acknowledges that fishing Murray cod primarily for food is a priority reason for pursuing this species, together with the recreational, sport and other aspects of the spectrum of activities, often lumped under the banner "recreational fishing" (Kearney, 1999a).

Murray cod are targeted throughout their range in the Queensland component of the Murray-Darling Basin, but fishing by Queenslanders is concentrated around the New

South Wales border. Fishing has been relatively good in at least two of these rivers, the Dumaresq and Severn, in the last five years. Even though the sample size is small the size composition of fish taken in these rivers appears to be around a mean of approximately 50cm, with no evidence of a significant pulse of smaller fish (Figures 3a & b). Data from a small number of fish (43) tagged in the Condamine River since 1996 suggests similar size distribution (Figure 3c).



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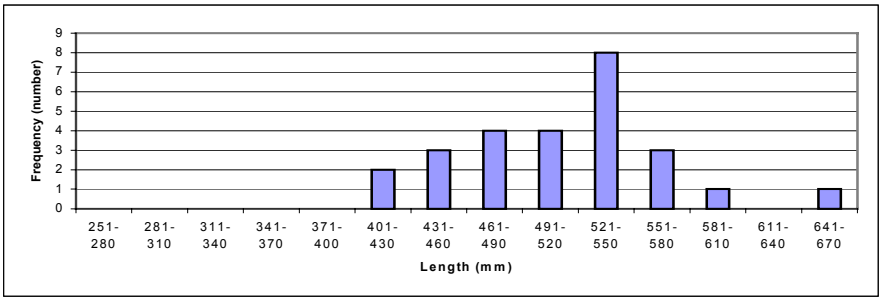

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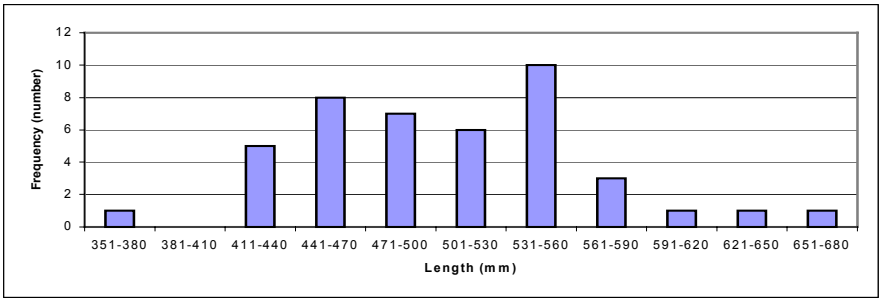


(c)

Figure 3: Length frequency histograms for recreational catches of Murray cod from: (a) all areas of Queensland, 1991-2000, (b) all areas of Queensland, 1999, and (c) the Condamine River, 1996-2000 (Data from Sawynok, *pers. comm*., 2001).

Preliminary figures from Queensland-wide phone surveys of anglers provide an estimate of a state-wide annual catch of 22,500 Murray cod, approximately 10,000 of which are retained and 12,500 released (Higgs, *pers. comm*., 2001). These figures, together with the limited catch and size data available (Figures 3a-c), suggest an annual take of approximately 30 tonnes, and confirm reports from anglers that most legal size cod are retained and eaten.

Murray cod fingerlings are regularly stocked by the Fisheries Department and angler and conservation groups into a large number of dams, weirs and rivers in the western drainage (Table 4).

Table 4: Dams and weirs regularly stocked by the Queensland Fisheries Department (from Jackson, *pers. comm*., 2001).

Impoundment & Associated River	*Impoundment & Associated River*
Beardmore Dam – Balonne River	Chinchilla Weir – Condamine River
Connolly Dam – Rosenthall Creek (Condamine River)	Dalby Weir – Condamine River
Cooby Dam – Oakey Creek (Condamine River)	Goondiwindi Weir – Macintyre River
Coolmunda Dam – Macintyre Brook (Dumaresq River)	Jack Taylor Weir – Balonne River
Glenlyon Dam – Pine Creek (Dumaresq River)	Miles Weir – Condamine River
Gundi Lagoon – Balonne River	Neil Turner Weir – Maranoa River
Leslie Dam – Sandy Creek (Condamine River)	Surat Weir – Balonne River
Storm King Dam – Quart Pot Creek	Warrago Weir – Warrago River

Murray cod have also been deliberately translocated to two dams in the eastern drainage; Boondooma Dam on the Burnett River and Fairbain Dam in the Fitzroy Dawson catchment (Jackson, *pers. comm*.).

There is little argument with the conclusion that cod populations in Queensland have undergone serious declines. Habitat loss, manifest in many forms but particularly siltation, has been suggested by angling representatives and researchers to be the single greatest reason, although pollution from agriculture is also blamed for much of the decline (see also Section E.3 below). Stocking programs have masked natural

recruitment failures. The long-term implications of imbalance between natural recruitment and stocked populations are unknown.

B.2. New South Wales

The natural distribution of Murray cod encompasses all of the major New South Wales rivers in the Murray-Darling Basin. By 1980 combinations of cod habitat degradation, barriers to migration of the species, pollution in many forms, reduced river flows, increased exotic species and targeted fishing by commercial and recreational interests and illegal netting and trapping by poachers had reduced cod abundance dramatically. During the biggest survey of New South Wales freshwater fishes, in the mid 1990s (Harris & Gehrke, 1997), Murray cod were found to be no longer common in many areas of New South Wales, and were rare in the Murray and Murrumbidgee Rivers.

Relatively good records of commercial catches of Murray cod have been maintained by NSW Fisheries. These catches are summarised in Figure 4. It should be noted that the area in which the commercial fishery for cod was permitted to operate has been progressively decreased, with the fishery restricted to approximately 5% of New South Wales inland river systems by 2000. The total closure of the commercial fishery for native finfish species is scheduled for September 2001.

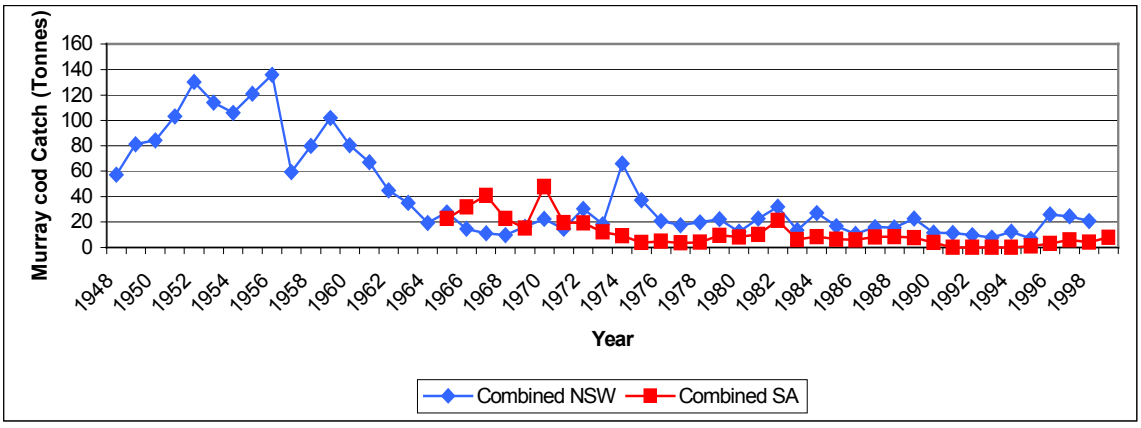
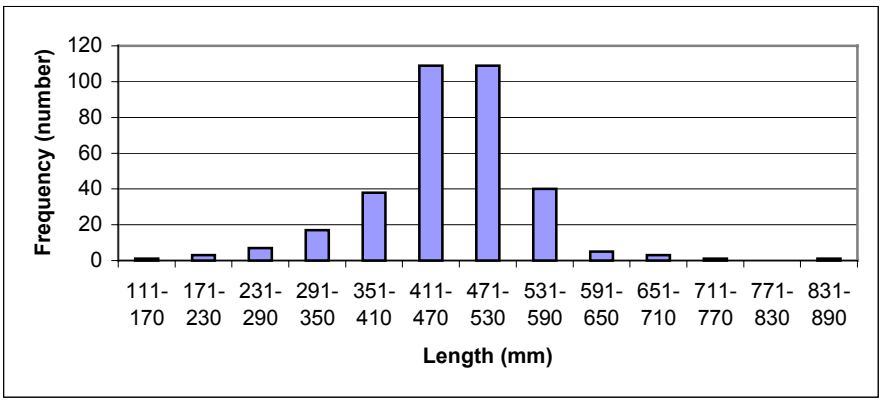


Figure 4: Catches of Murray cod by the New South Wales and South Australian commercial fisheries.

Recreational catches of cod have historically not been well monitored. However since the mid 1990's organised angling tournaments and competitions have begun to provide catch information, particularly size composition of catches, which is becoming useful for the monitoring and assessment of cod populations. Summaries of some of the more meaningful size composition data are provided in Figure 5 (a & b). Additional data on recreational tournaments is given in Appendix A.



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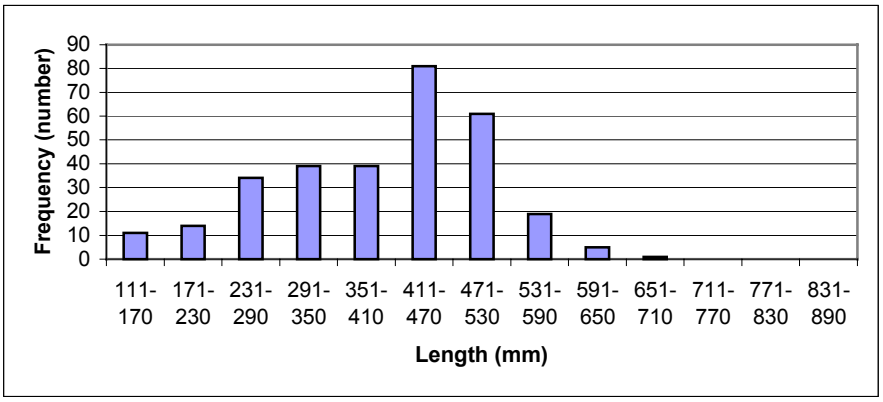


(b)

Figure 5: Length frequency histograms for catches of Murray cod for the combined Freshwater Masters and the Mulwala Classic (both conducted in Lake Mulwala) in (a) 1999 and (b) 2000 (Data from NSW Fisheries).

A current national survey of recreational fishing participation and catches has provided the first preliminary quantification of the extent of angler effort for, and catch of, Murray

cod throughout New South Wales. Data from this survey are summarised in Table 3a and 3b (Section A.5.3 above).

Since 1990 there has been a great increase in the stocking of New South Wales waters with hatchery produced Murray cod fingerlings. Fingerlings produced from the government-operated hatchery in Narrandera have gone exclusively to impoundments (Table 5) but private interests, predominantly angling groups, have been increasingly stocking rivers (Appendix B). Stocking has now become extensive with in excess of 370,000 fingerlings stocked in New South Wales each year.

Table 5: Production and stocking locations of Murray cod from the Narrandera Fisheries Centre, 2000-2001 (Data from NSW Fisheries).

Location	***River System***	***Nearest Town***	***Date Stocked***	***Number***
Burrinjuck Dam	Murrumbidgee River	Yass	16 December 2000	40,000
Yass Weir	Yass River	Yass	16 December 2000	4,000
Chinaman's Dam	Lachlan River	Young	17 December 2000	1,000
Pindari Dam	Severn River	Inverell	18 December 2000	40,000
Wyangala Dam	Lachlan River	Cowra	4 January 2001	40,000
Googong Dam	Queanbeyan River	Queanbeyan	4 January 2001	20,000
Lake Urana	Billabong Creek	Urana	5 January 2001	4,000
Bowman's Lagoon	Murrumbidgee River	Wagga Wagga	5 January 2001	3,000
Burrendong Dam	Macquarie River	Wellington	11 January 2001	10,000
Total				**162,000**

The long-term decline in commercial catches (since the 1940s, Figure 4) has in the absence of more accurate data, been used as an index of the relative abundance of cod and the best indicator of the plight of the species. Following a detailed analysis of commercial catch and effort data and other available records, Reid *et al*. (1997) concluded that the data were not adequate to enable meaningful quantitative stock assessment. They highlighted the need for more detailed catch-at-age data and better understanding of the biology of the species. Furthermore, the variable and restricted distribution of the commercial fishery restricts the relevance of this data set to

assessments of the total Murray-Darling system. For all its limitations it remains, however, the best single indicator of long-term trends in the relative abundance of Murray cod in the New South Wales sector of the Murray-Darling Basin.

B.3. Australian Capital Territory

As the ACT is geographically totally within New South Wales and is also on the upstream (highland) extreme of the distribution of Murray cod, assessment of the limited information available on this species in the Territory has been incorporated into the New South Wales and Basin-wide assessments.

There is no commercial fishery for Murray cod in the ACT and no structured data have been collected on the recreational fishery. In 2000/01, 69,000 Murray cod fingerlings were purchased by the ACT Government from New South Wales commercial hatcheries and stocked into ACT impoundments.

B.4. Victoria

The status of Murray cod in Victoria is as expected, similar to that of the River Murray regions of southern New South Wales. Exploitation of the species differs primarily in that there is currently no targeted commercial fishery for the species in Victoria. It is legal for Victorian commercial fishers to land and sell Murray cod, but the geographical restrictions on the commercial fishery are such that Murray cod catches by commercial fishers are insignificant.

The long-term declines in cod populations in New South Wales and South Australia documented from commercial catch records (Figure 4) have been paralleled in Victorian waters.

Recent reports from recreational fishers and research representatives in Victoria confirm the increased abundance of small Murray cod, and other native species including trout cod and even silver perch, in the last few years. It is accepted that most of this pulse in recruitment is due to improvement in the timing and volume of river flows, but as there

have been significant stockings of hatchery produced fingerlings in recent years (see for example Table 6a & b) the impacts of natural recruitment and stockings on apparent abundance of small Murray cod have been confounded.

Table 6a: Departmental Stocking Program for Murray cod by Fisheries Victoria, 1999/2000 (from DNRE, Victoria).

Water Stocked	*Month/Year*	*Average weight of released fish (g)*	*Number of Murray cod released*
Broken Creek	January 2000	1.0	1,000
Cullulleraine Lake	January 2000	0.8	10,000
Goulburn River (Toolamba-Shepparton)	March 2000	1.7	21,000
Hume Reservoir	January/February 2000	0.6-1.0	50,000
Lindsay River	January 2000	0.99	20,000
Loddon River (Ferrihurst Weir)	January 2000	0.8	10,000
Mokoan Lake	January 2000	0.8-1.0	20,000
Taylors Lake	January 2000	n.a	8*
Wimmera River (Elmburst)	January 2000	0.96	5,000
Total			**137,008**

*Mature fish salvaged from Green Lake
Note: all fish were chemically imprinted to enable identification as stocked fish when recovered in future stock assessment programs.

Table 6b: Authorised Client Group Fish Releases of Murray cod, 1999/2000 (from DNRE, Victoria).

Water Stocked	*Client Group*	*Month/Year*	*Average weight of released fish (g)*	*Number of Murray cod released*
Eildon Lake	Futurefish Foundation	March, 2000	0.8	8,000
Eppalock Lake	Bendigo Field & Game Association	January, 2000	n.a.	5,000
Wimmera River (Glenorchy)	Stawell & District Angling Club	March, 2000	2.15	2,000
Total				**15,000**

The aquaculture industry for Murray cod in Victoria continues to grow, producing both fingerlings for stocking and fish for human consumption. The state's current production for human consumption, in excess of 70 tonnes per annum (Table 2), is already approximately double the total production from the commercial capture fisheries from the whole of the Murray-Darling Basin.

B.5. South Australia

Murray cod is of great importance to both commercial and recreational fisheries in South Australia. The commercial fishery is dominated by catches taken directly from the River Murray (94%). Only 35% of the total length of the South Australian section of the River Murray is open to commercial fishing. The whole of the river is open to recreational fishing.

The commercial catch of cod reached a peak of approximately 150 tonnes in the late 1950's, then progressively declined to single digit figures in the late 1980's leading to a closure of the fishery in 1990. The fishery was re-opened in 1994 and since then catches increased to a high of approximately 20 tonnes in 1999/2000 (Ye *et al*., 2000).

The increased catches since the early 1990's are attributed to a few strong year classes, which followed the floods in 1989 and early 1990s. However, the current fishery remains dependent upon these few, relatively strong, year classes with little evidence of strong subsequent recruitment (Ye *et al*., 2000). The pulse of good recruitment reported in New South Wales over the last five years is not reflected in South Australia. South Australian fishers (recreational and commercial) confirm that fish of approximately 50 cm, and above, in length continue to occur but with few fish below that length. Fish of 50 cm would likely be attributable to recruitment arising from the increased flows, which resulted from the major releases of water from the Hume Weir in late 1996 but their relatively low numbers suggest this event had only a marginal impact on cod recruitment in South Australia. Larger fish have carried over from recruitment following the flood events from 1989 to 1994.

The analyses of available catch and effort data and correction of these figures for the impacts of river flow (Ye *et al*., 2000) represent the most sophisticated stock assessment of Murray cod in Australia to date. While the authors appreciated the limitation of the data at their disposal, these analyses provide a most valuable contribution to the ongoing assessment of the species.

The size composition data presented by Ye *et al*. (2000) (Figure 6) tends to over-represent the decline in relative abundance of small cod entering the commercial fishery because some fishers voluntarily released fish less than 60cm in length in the last few years (Coombs, *pers. comm*., 2001 & Pierce, *pers.comm*., 2001).

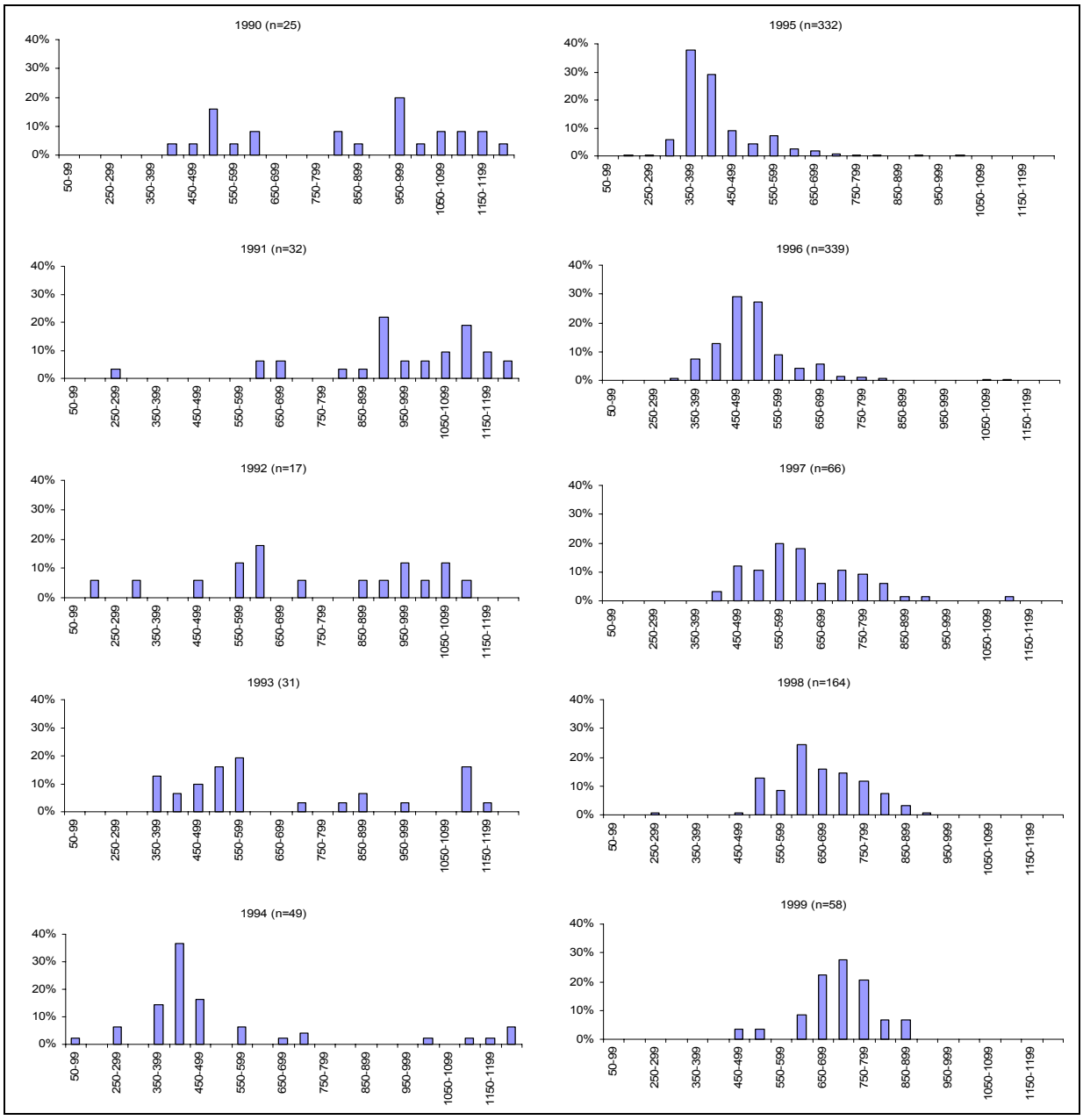


Figure 6: Length frequency distributions (percent frequency) of Murray cod from a voluntary fish length reporting program of the commercial fishery in South Australia from 1990 to 1999 (from Ye *et al*., 2000). All lengths are in millimetres.

No data were available on the recreational fishery.

C. RIGOUR OF PREVIOUS SAMPLING AND ANALYTICAL TECHNIQUES

Data that have proven useful in the assessment of the status of Murray cod can be categorised as historical descriptions, commercial fisheries data, recreational fisheries data, environmental data, and interviews and anecdotal information. Historical records are assumed to be reliable accounts of impressions of early European explorers and settlers. They provide the only record of perceived abundance of Murray cod and traditional Aboriginal use of the species prior to "development" of the Murray-Darling system, and as such they represent a useful indicator of the social perceptions of unexploited abundance.

The data available on commercial fisheries are largely restricted to catches by total weight, and some indications of the number of participants. The lack of size/age composition of catches and precise geographic information on fishing activities seriously detracts from their value in analyses. No estimates of under, or over, reporting of catches or of bias in declarations are available. Nonetheless, they remain the best available indicator of long-term changes in cod abundance. The fact that major peaks in reported catches can be back-correlated with major environmental events (floods and droughts) is confirmation that they do at least reflect relative abundance over a long time period.

The few data that are available on recreational fisheries are almost exclusively restricted to the last decade. Their value is therefore largely restricted to describing current practice, rather than historical trends. The current national survey of recreational fishing (see for example Table 3a & b) is the first of its kind in Australia, and enables the first structured quantification of total recreational cod catches and fishing effort. The sample size is by necessity, small, resulting in very large raising factors with resultant limited precision. The real value of the data is as the first structured assessment and as a reference point for future assessments.

Size composition data from angling tournaments (for example Figures 5a & b and Appendix A) are beginning to provide valuable information on relative size distributions

in key areas, and as indicators of spawning success and future recruitment. Fishing effort and total catch data from these same tournaments will increase in utility, particularly if targeting practices and fishing techniques can be maintained relatively consistent.

The almost complete lack of data on unlicensed commercial catches and poaching with illegal traps and drum nets (considered particularly prevalent by riparian land holders) is of great concern. There are no published estimates of catches by such harvesting, but reports of dozens of traps (predominantly wire drum nets) in many local river reaches suggests that the total number of such devices used in the Murray-Darling Basin would be in the thousands. This assumption is supported by state fisheries researchers and managers, anglers and licensed commercial fishers. Fisheries officers from NSW Fisheries confiscate hundreds of such traps each year (Sanger, *pers. comm*., 2001) as do fisheries officers from South Australia (Zacharin, *pers. comm*., 2001). As these devices can be extremely effective, particularly in times of elevated river flows when fish are on spawning migrations, total catches probably greatly exceed the total commercial catch or even the total recreational catch. It is also argued that wire traps cause considerable abrasion to fish therein. Thus they represent a potential cause of mortality, both short-term and through increased vulnerability to disease, even to those fish that escape or are released. As they are often made of small mesh (chicken wire) the catch of under-size fish is relatively high. Furthermore, they are not designed or used in a manner conducive to optimum health of fish that are caught but not targeted (by-catch).

Data on the numbers and placement of cod fingerlings used for stocking have improved markedly in the last few years. However, there is still no process of assessing the anticipated impact of such stockings before fingerlings are released, or of evaluating impact after releases. In view of the key role of cod in riverine ecosystems, such assessments appear essential. Cod are apex predators and their impact on other species is considerable. The impact of stocking on wild cod populations and on the genetic integrity within the species are other ecological reasons impact assessments would be most valuable. The very real possibility that the broadcasting of cultured fingerlings could spread disease also warrants investigation. It would, of course, also be valuable for

managers to be able to assess the true impact, including cost-effectiveness, of stockings on angler catches which after all, remains the primary reason for most stockings.

Hydrological data on the Murray-Darling system have been collected and collated by a number of state agencies and by the Murray-Darling Basin Commission. The data available appear more than adequate to facilitate investigation of water quality and quantity factors that influence the well-being of Murray cod populations; the primary limitation to such analyses would likely be the paucity of the data on cod biology and behaviour. However, assessment of the rigor of sampling and data analysis for hydrological data is beyond the scope of this present study.

C.1. Alternative Sampling Techniques

It is clear that current data do not enable stock assessment of the precision required for modern fisheries management. With the cessation of the commercial fishery for Murray cod in New South Wales in September of this year, the largest and arguably the most valuable set of data for monitoring population trends will be terminated. Notwithstanding the fate of the commercial data-base a more reliable and geographically representative monitoring tool(s) is essential. Well-structured recreational fishing tournaments provide one source of length frequency sampling and potentially valuable catch and effort indices, however the geographic and temporal distribution of such structured tournaments is currently grossly inadequate. Even with a reasonable grid of structured tournaments, a Basin-wide industry independent survey appears essential. The New South Wales Rivers Survey (Harris & Gehrke, 1997) has given an excellent foundation on which to build.

Monitoring of the genetic integrity of cod stocks and the ecosystem impacts of stocking programs require new processes. There is adequate scientific knowledge of fisheries ecosystem sampling in the collective state, territory and Commonwealth fisheries and environment agencies to design appropriate protocols. Research currently underway in Queensland and New South Wales may well assist.

D. TRENDS IN THE NUMBER AND DISTRIBUTION OF MURRAY COD IN THE MURRAY-DARLING BASIN

There is no doubt the relative abundance and geographic distribution of Murray cod have declined dramatically across the Murray-Darling Basin. Catch data from the commercial fisheries in New South Wales and South Australia (Figure 4) provide a graphic approximation of fluctuations and declines. The lack of age composition data, or even size composition, and fine-scale geographic location of catch and effort information makes more quantitative analyses of this information currently inappropriate.

It has been established since at least the 1970's that recruitment success by cod is directly linked to river flow, with a rise in water temperature and flood events being key triggers for spawning and subsequent recruitment respectively (see section A.4.1 above). Accordingly, analyses of river flow data from the lower Darling River at Burtundy, from the New South Wales section of the River Murray at Euston, and from the combined flows of the Darling and Murray rivers into South Australia; at Lock 6 on the River Murray (Figure 7), provide several plausible explanations for the recruitment pattern observed since 1990 by recreational and commercial fisheries.

The limited size-composition data from the South Australian commercial fishery and the data now emerging from recreational fisheries in New South Wales and Queensland (Figures 5a & b), together with verbal reports from the many people contacted during this study provide some insight into the recent trends in recruitment of Murray cod.

In the lower Darling River and New South Wales reaches of the River Murray, small fish have been unusually abundant in the last four or five years. While flow data from the lower Darling shows several pulses since 1996, flows in the New South Wales River Murray were low from the Hume Weir event of late 1996 to the end of 2000 (Figure 7). Recruitment in the South Australian reaches of the River Murray was relatively strong following the flood events of 1989-94 but has been minimal since then. There is a suggestion that the major releases of water from the Hume Weir in late 1996 may have resulted in only marginal recruitment in South Australia, even though this same event

appears to have triggered significant recruitment in the New South Wales section of the river.

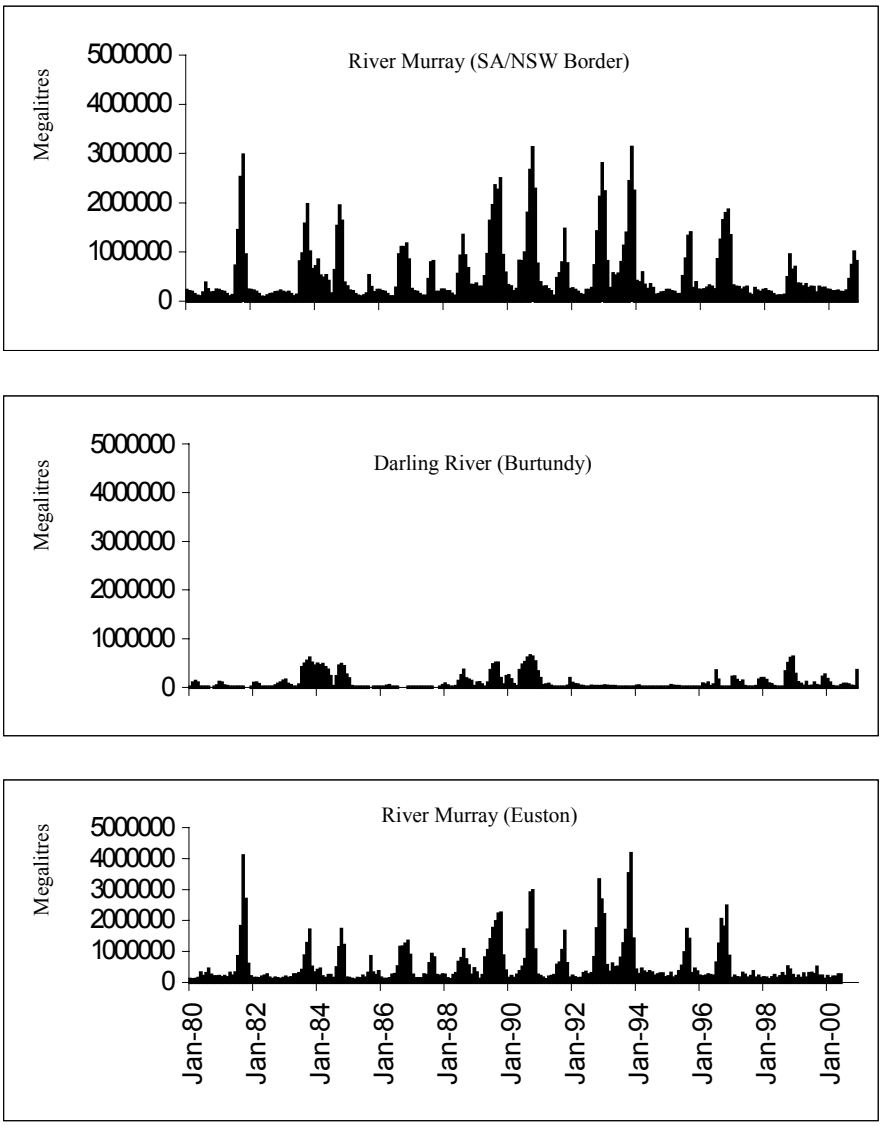


Figure 7: Flows (megalitres per month) reaching South Australia (top) from the Darling River at Burtundy (middle) and the River Murray at Euston (bottom). Figure prepared from data provided by the Murray-Darling Basin Commission.

The strong recruitment observed in South Australia from the early 1990's can clearly be linked to four periods of very high flow between 1989 and 1994 inclusive (Figure 7). All four of these events had peak monthly water flows well above 2,000,000 megalitres. The strongest recruitment appears to correspond to the 1989 and 1990/91 events which perhaps significantly, resulted from increased flows from the River Murray in New South

Wales and from the Darling River. The 1996 event, which produced strong recruitment in New South Wales, but not in South Australia, did not exceed 2,000,000 megalitres in any one month at the NSW/SA border, nor did it coincide with a major increase in contribution from the Darling River.

Strong recruitment may be more directly linked to some characteristic of increased flows other than maximum monthly flow, for example precise timing of the increase, the duration of flows or the quality, including temperature, of the water delivered. The obvious strong correlation between flow and subsequent commercial cod catch, dating back approximately one hundred years, necessitates detailed analyses beyond the scope of the present project. Subsequent river management practices may then be guided by the flow requirements for effective cod recruitment but will also need to accommodate the needs of other native fish species. As several of these other species are more endangered than are cod, they may even need preferential water allocation.

E. MAJOR THREATS TO THE SURVIVAL OF MURRAY COD

Threats to the survival of Murray cod can be divided into three categories: threats to the persistence of the species (species biodiversity); threats to the genetic integrity of the species (genetic biodiversity); threats to the integrity of the ecological systems to which the species contributes (ecological biodiversity).

E.1. Threats to species persistence

Murray cod is the only one of the four members of the genus *Maccullochella* that is not formally listed as threatened. While natural populations of Murray cod have been dramatically reduced the species is very widely distributed and even remnant populations have in several cases, been shown to be able to produce reasonable recruitment. General acceptance in recent years, of the plight of populations of numerous species of native freshwater fish, by natural resource managers, and growing public awareness and concern for the icon species, Murray cod, appear likely to guarantee greater protection. Furthermore, artificial propagation of the species for restocking and as the basis of a

growing aquaculture industry has developed to the point that extinction of the species is no longer an immediate threat.

Persistence of the species is not of major concern but survival and integrity of wild populations are seriously threatened.

E.2. Threats to species integrity

The effective partitioning of the Murray-Darling Basin through the creation of many barriers to fish migration (dams, weirs and locks) represents a serious threat to the genetic integrity of the species. Murray cod are regarded as historically one genetic population (Pierce and Doonan, 1999). However, existing stocks are becoming more fragmented and physically isolated leading to the potential for local erosion of genetic variability through genetic drift.

Artificial propagation of cod for restocking and aquaculture also poses serious threats to the genetic integrity of the species in the wild. Artificial translocation of genetic material is already occurring through organised and *ad hoc* stocking programs, often government sponsored or sanctioned, and while government hatcheries adhere to protocols which limit broodstock to wild-caught fish, practices in private hatcheries are less well documented. Even governments have been responsible for deliberate stocking of Murray cod outside their normal distribution (for example east of the Great Dividing Range).

The consequences of translocation of stocks are not always clear. On the one hand, translocation may assist in maintaining or increasing genetic diversity locally, compensating for the effects of isolation through habitat fragmentation. On the other hand, adaptation to local conditions may be disrupted by the introduction of stock from distant sources or sources unknown. Data are simply not available to assess the full consequences of restocking from non-local sources or of stocking fish which were derived from "local" stock but subjected to some form of selection pressure (deliberate or accidental) in the breeding, hatching, rearing and stocking processes.

As the aquaculture industry for Murray cod as a table fish increases, the selection of broodstock for "aquaculture friendly" characteristics, such as rapid growth, easy handling or good conversion of artificial feeds, is certain to be an issue for the future conservation of the genetic integrity of the species. Aquaculturists will need regulation to ensure fingerlings used for stock enhancement are only from appropriate broodstock. Strong artificial selection for rapid growth and large body sizes may be desirable in the aquaculture industry and by angling groups wishing to gain access to faster growing individuals, but may produce sub-optimal genotypes under natural selective regimes. Restocking with such genetically modified forms would be regarded as a form of genetic pollution, potentially reducing the overall viability of natural stocks. Pressure from angling groups for access to faster growing individuals, or those with other 'desirable' traits, will need to be managed.

Accidental transmittance of disease through aquaculture and stocking practices, and resulting impact on genetic diversity must also be considered.

E.3. Threats to ecological integrity

As the apex aquatic predator in the Murray-Darling system, Murray cod is a unique contributor to the aquatic ecosystem and the outstanding indicator of the total well-being of that system. The life history of Murray cod and the differing requirements of eggs, larvae, juveniles and adults necessitate integration of many aspects of habitat availability, water quality and quantity and impacts of directed targeting. As a high level consumer it provides a good indicator of overall system health, integrating the impacts of water resource development and habitat modification on lower trophic levels. Its complex life history with widely varying requirements of different life history stages, is such that it can also be regarded as an umbrella species. Catering for Murray cod in management will bring a range of attendant benefits to other species with similar or less stringent habitat requirements. Managing for Murray cod will equate to managing for ecosystem integrity.

A recent review of the threats to Australia's freshwater ecosystems (Davis *et al*., 2000) identified from a national survey of a spectrum of interests in freshwater use and

management, a total of 41 threats which, through a process of expert panel review, could be condensed to six principal categories (Figure 8). These threats, in priority order, were habitat degradation, pollution, reduced environmental flows, barriers to migration, introduced species, and fishing. While the relative priorities of these threats, and the 41 components thereof, are debatable, there is no argument that they collectively represent the major threats to the integrity of the ecological systems to which Murray cod contribute.

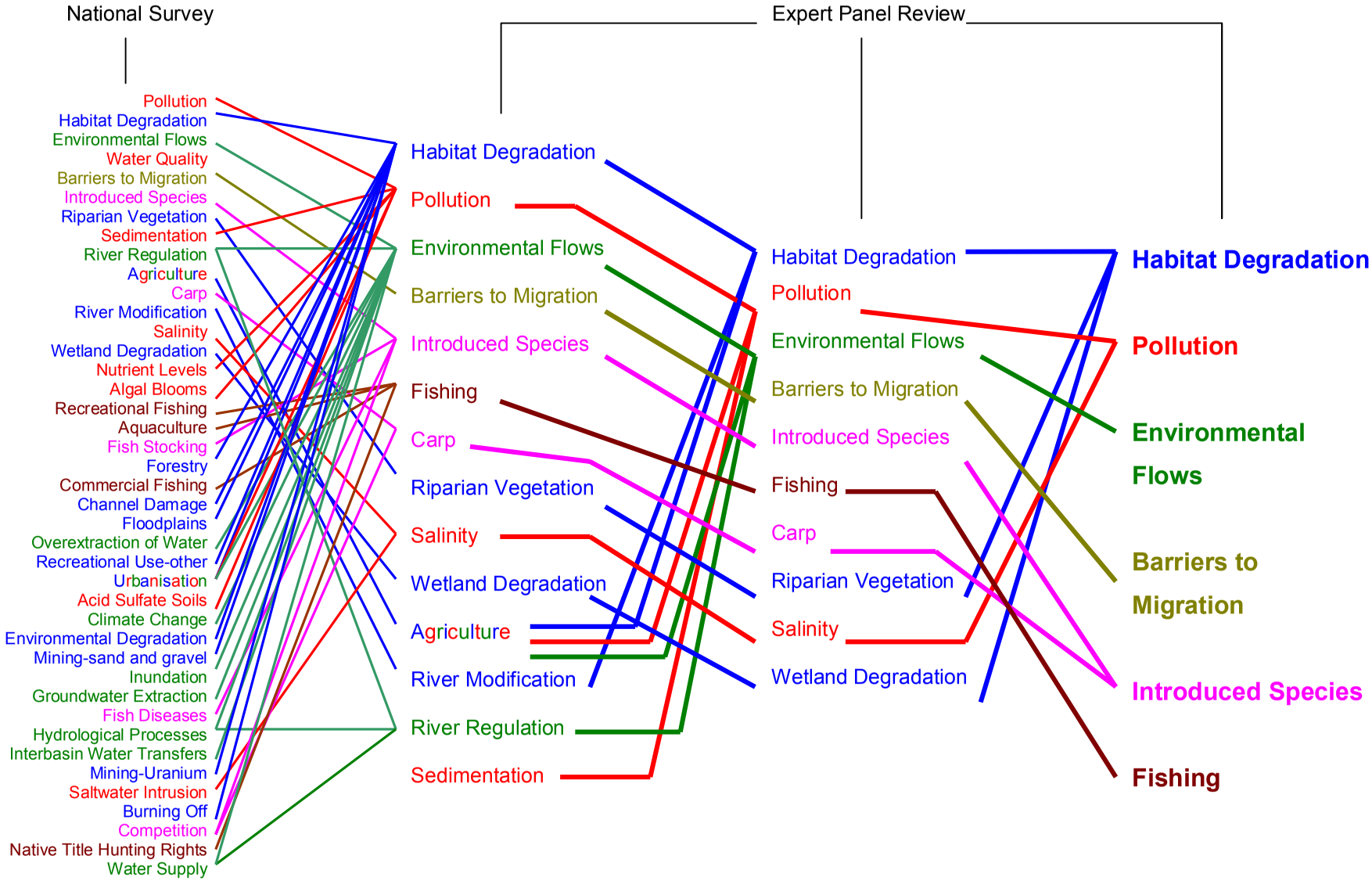


Figure 8: Merging by a process of expert panel review, threats to freshwater ecosystems identified in a national survey (from Davis *et al.*, 2000).

F. CURRENT CONSERVATION STATUS

Both the scientific and general community have expressed concern over the decline in numbers and distribution of Murray cod (Koehn, 1996a). Although the species is still popular with anglers and commercial fishers, and good catches continue to be taken in some places, the frequency of large catches is a far cry from what it was in the early 1900's (Gehrke & Harris, 2000). Despite this, of Australia's four closely related species of freshwater cod – Murray cod, trout cod, Mary River cod and eastern cod – Murray cod is actually the most abundant, and least threatened, with the others classified as "endangered" (Koehn, 1995; ASFB Inc., 2000).

Murray cod is currently listed as "Vulnerable" in Victoria (Morris *et al*., 2000), and the status is described as "fully exploited" in South Australia (Ye *et al*., 2000). However, this species remains unlisted on the 2000 IUCN Red List, the ASFB and ANZECC, as well as in all other States (Morris *et al*., 2000).

Suggestions have been made that current listings are not adequate to prevent the declining distribution and abundance of this species. Morris *et al*. (2000) suggests that Murray cod be listed as "Lower Risk (near threatened)" under the IUCN Red List of threatened species, "Restricted" under the ASFB Threatened Fish Listings and "Conservation Dependent" under the Commonwealth's Environment Protection and Biodiversity Conservation Act, 1999.

As discussed above (section E) Murray cod as a species does not appear endangered at present. Far greater pressure exists on the genetic integrity of the species and on the ecosystems of which Murray cod is a key component. The current push by NSW Fisheries and the Victorian Department of Natural Resources and Environment to have the ecosystem of the lower River Murray classified as threatened, rather than simply classifying individual species, appears appropriate.

G. MAJOR KNOWLEDGE AND POLICY IMPEDIMENTS TO SUSTAINABLE USE AND MANAGEMENT OF MURRAY COD

It is well accepted that the precipitous declines in populations of native fish species throughout the Murray-Darling Basin are due to a suite of anthropogenic influences, of which targeted fishing is but one. A recent review of the threats to Australia's freshwater fisheries and the ecosystems which underpin them (Davis *et al*., 2000) suggests that fishing is indeed ranked only sixth behind a spectrum of habitat and environmental factors (see E.3 above). Regardless of the ranking given to individual threats to fish and ecosystems, it is clear that the sustainable use and management of Murray cod must be conducted in concert with the ecologically sustainable use of freshwater ecosystems, underpinned by the wise and informed management of the water itself.

The knowledge requirements and policy impediments for the sustainable use and management of Murray cod cannot be divorced from those for the overall water use and ecosystem management of the Basin. Policies for their protection must therefore, be cognisant of all competing demands for water and terrestrial environments.

G.1. Knowledge Requirements

In the recent review of the knowledge requirements to address impediments to the management of freshwater ecosystems, Davis *et al*. (2000) provided a listing in priority order for each of the six major threats (Table 7).

Table 7: Knowledge required to address the six major threats to freshwater fisheries (from Davis *et al*., 2000).

Threat	*Knowledge required to address the threat*
Habitat degradation	National inventory of fisheries species as indicators of river & fishery health
	Knowledge of the extent of habitat degradation
	Biological & habitat information for fish & invertebrates
	Indicators for use in adaptive management
	Identify data to be collected by community groups in national inventory of indicator fish species
	Understanding of processes driving rivers & their interactions with ecosystems
	Amount of habitat requiring rehabilitation for there to be a positive reaction from the ecosystem
	Carrying capacity of various habitat types & methods for demonstrating the value of habitat
	Identify appropriate community groups to collect data in a national inventory of fish species
	Methods to improve artificial impoundment's for fish
	Mechanisms & incentives for achieving action from managers
Pollution	Use of species important to fisheries as indicators of the effectiveness of pollution management
	Understanding the extent of direct & indirect impacts on ecosystems
	The link between pollution, the resource & the responsible parties
	Understanding of effective restoration methods
Reduced environmental flows	The extent & effects of private dams, both on- & off-stream
	Methodologies for indicative assessment of flow requirements
	The response of the ecosystem to environmental releases
	The social & economic costs/benefits of providing environmental releases
	Responses of fish & fisheries as indicators of the effects of environmental flow management
	Information on the biology of fish species relevant to environmental flows
	Ways to create incentives within communities & politics for implementation of increased flows
	Understanding of natural variability & its impacts
	Understanding of flow-related interactions within the ecosystem
	Examination of agricultural water use & a cost/benefit analysis of such use
Barriers to migration	Appropriate fishway design & assessment of the effectiveness of alternative designs
	Methodologies for determining fish passage requirements
	Information on the biology of fish species relevant to fish passage
	Understanding the relationship between controlled releases & the time of use of fishways
	Benefits/costs associated with provision of fish passage, including removal of barriers
	Methods to allow fish past high structures (>4m)
	Cost-effective ways to allow fish past low barriers
Introduced species	Cost effective methods of control
	Methods to assess potential threats/uses
	Studies of population dynamics to determine which control methods may be successful
	Understanding of the impacts of introduced species
	Ways of increasing public awareness of the problems associated with introductions
	Effect of removing an introduced species
	Ways of minimising the movement of fish between catchments
Fishing	Description of indigenous fisheries & their cultural significance
	Status of the resource, including stock assessment & population dynamics
	Social & cultural significance of fishing to communities
	Cost/benefit analyses of alternative resource allocations
	Details of which fish are taken where
	By-catch avoidance methods
	The pristine stock biomass & carrying capacity of at least representative areas
	Cost effective methods to determine if the fish that are caught are wild or stocked

This listing is still current and relevant. Below are listed, but not prioritised, a number of knowledge requirements which are particularly relevant to Murray cod and/or require additional emphasis as a result of information gathered in the preparation of this report:

- Better definition of the cultural significance and heritage value of Murray cod, particularly in relation to indigenous people and smaller riparian communities.
- Better indicators of spawning and recruitment success across the Basin.
- More detailed assessment of the hydrological factors which trigger spawning and support successful recruitment.
- Better understanding of the relationships between successful recruitment for cod and for other native species.
- Understanding why some cod populations have failed to recover even though relic populations have remained, restocking has occurred and the apparent major local causes of declines have been corrected (eg. upstream of Burrendong Dam on the Macquarie River).
- Better evaluation, assessment and monitoring of genetic integrity of individual cod stocks.
- Assessment of the impact on wild cod populations and broader aquatic ecosystems, of stocking of cod fingerlings.
- Quantification of the extent of illegal poaching of cod and identification of management strategies, including increased community education, to overcome the problem.
- Evaluation (quantification) of benefits and costs of recreational fisheries to local communities and to cod conservation throughout the Basin.

G.2. Policy Issues

The wisest management of all resources within the Murray-Darling Basin would necessitate catchment-wide consideration of issues and policies that acknowledge the need for total benefits even at the expense of local priorities. Reality reminds managers that the Basin encompasses parts of four states and all of the ACT, and that management of freshwater fisheries is vested with individual states and territories. Fisheries managers

feel further disenfranchised in that the primary drivers of the status of freshwater fish resources are anthropogenic issues beyond the control of the fisheries portfolio. Nonetheless, the benefits of Basin-wide policies, or at least complementarity among individual state and national policies, remain obvious. The Murray-Darling Basin Commission is testimony. For Murray cod, the apex aquatic predator historically distributed throughout the Basin, and only within the Basin, the benefits of total catchment management are exemplified.

It is therefore assumed that the policy issues for enhancing the sustainable use and management of Murray cod identified in this report, as listed below, would be most effectively addressed Basin-wide. If common policies are not possible, complementarity would help.

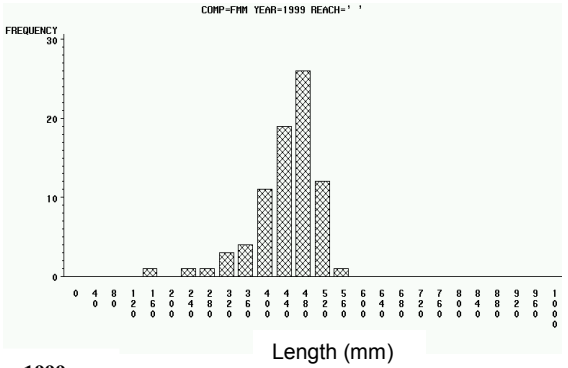
- There needs to be clearly stated objectives for the management and use of all native fish within the Basin. For example, conservation objectives to keep the spawning biomass across the Basin above levels known to produce strong recruitment when conditions are favourable and to rebuild total biomass to well-defined optimum levels, and objectives that clearly enunciate the principles for allocation of fish resources between consumptive, recreational and preservation interests. Clearly defined management strategies including management triggers and performance indicators should follow. (At the present time the risk of total extinction of the species appears the primary trigger for management action, and even then there is ample room for procrastination while it is considered what action is needed and by whom).
- Resource conservation principles and management triggers related to resource sustainability should be given priority over resource allocation issues, at least until the long-term security of the resource is assured.
- Management of targeted use, including allocation of Murray cod resources, should be aligned with the assessed impacts of each type of targeting (indigenous, licensed commercial, recreational and poaching) on the resource and underlying ecosystems and the costs (including management) and benefits (social, cultural and economic) of each harvest strategy.

- More effective management (elimination) of illegal use of traps and nets is required.
- Common policies and management objectives for recreational fisheries, which promote resource conservation and more equitable sharing of allocations within the recreational sector would improve the conservation status of recreational fishing. Examples could include a Basin-wide ban on set-lines, a common bag and possession limit of one or two Murray cod, prohibition of the use of live fish as bait and declaration of selected areas for total seasonal closures (not just for the taking of Murray cod). Incentives for collection of fishing effort and catch and length/age data, probably from structured recreational fishing events, would facilitate the monitoring of spawning and recruitment success. It would also give anglers a more active role in the assessment and subsequent management process.
- The stocking of hatchery produced fingerlings, particularly into rivers and flood-prone impoundments, requires regulation. Clear objectives, procedures for assessment of anticipated impacts and monitoring protocols are required urgently.

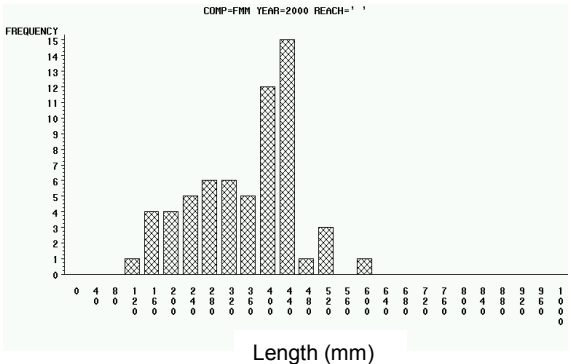
ACKNOWLEDGMENTS

A list of the people who were most generous with their time, for often lengthy and repeated phone conversations or personal interviews and in many cases, the supply of data, is held by Environment Australia. We are extremely grateful for their assistance. Dr. John Harris and A.Prof. Arthur Georges provided most valuable comments on a draft of this report.

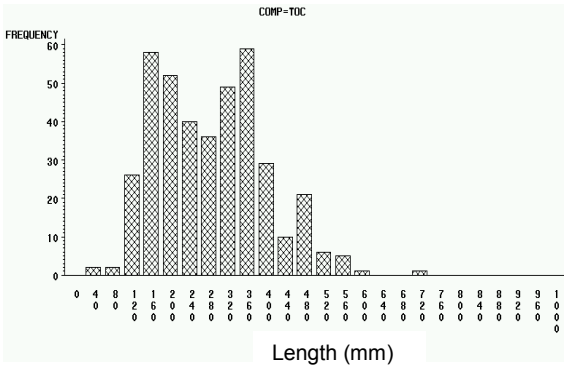
APPENDIX A: LENGTH FREQUENCY HISTOGRAMS FOR CATCHES OF MURRAY COD FROM NEW SOUTH WALES RECREATIONAL FISHING TOURNAMENTS.



1999

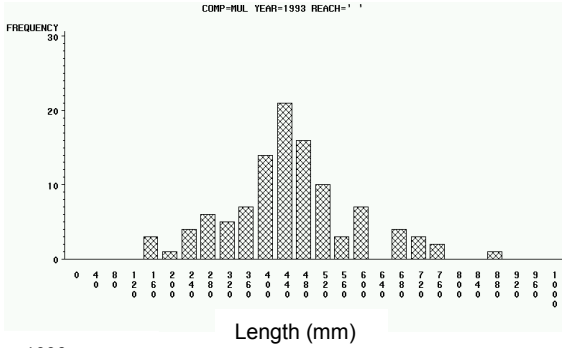


2000

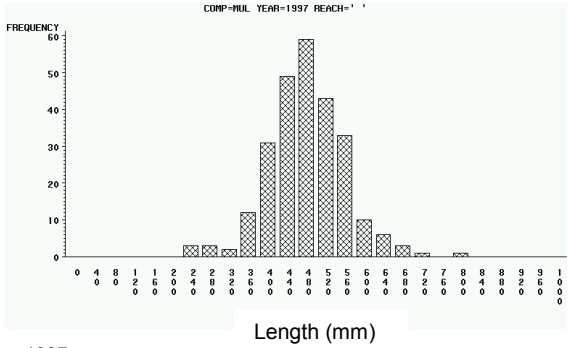


2001

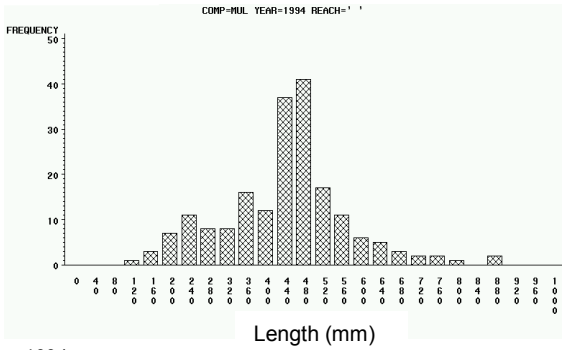
Figure A.1: Length Frequency Histograms of Murray cod caught from Lake Mulwala at the Freshwater Masters in 1999 (top) and 2000 (middle) and the Tocumwal Classic in 2001 (bottom).



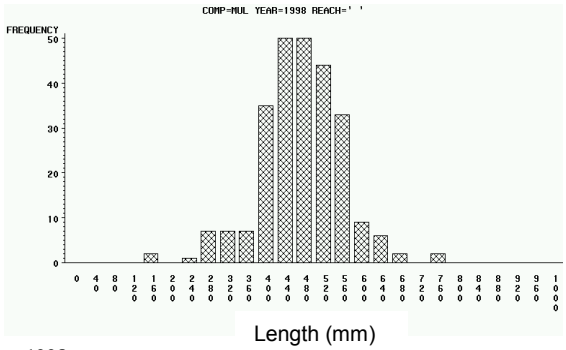
1993



1997



1994



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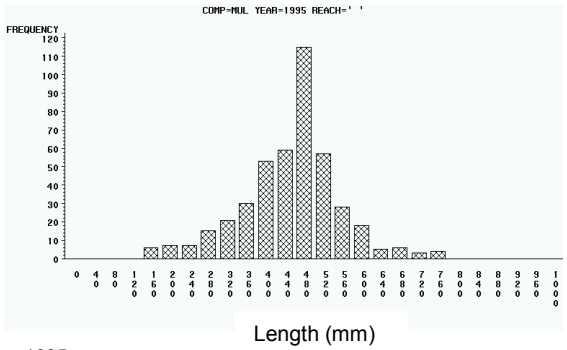
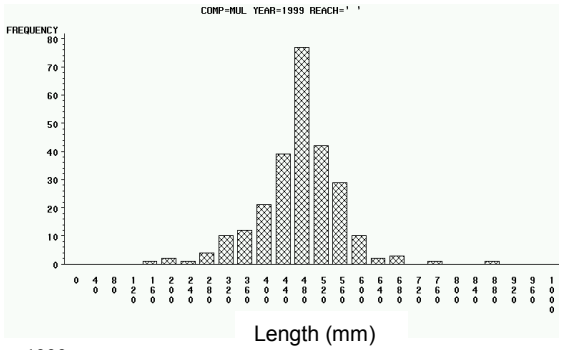


1995



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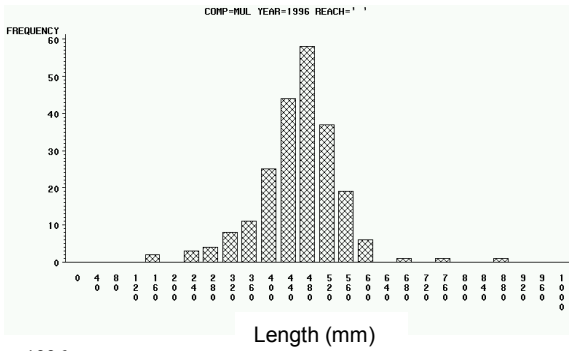

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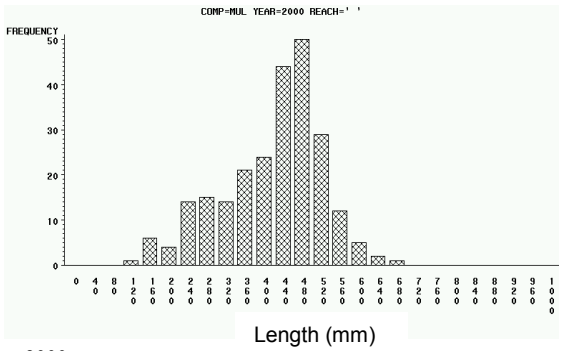
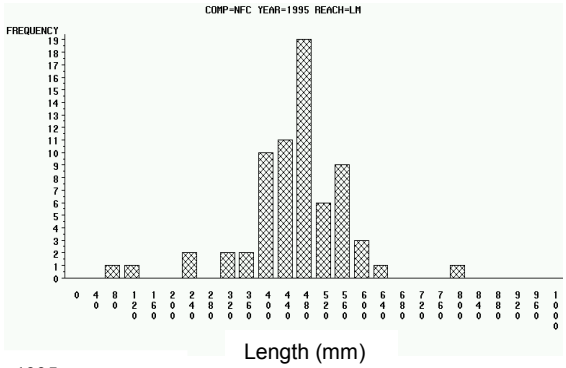
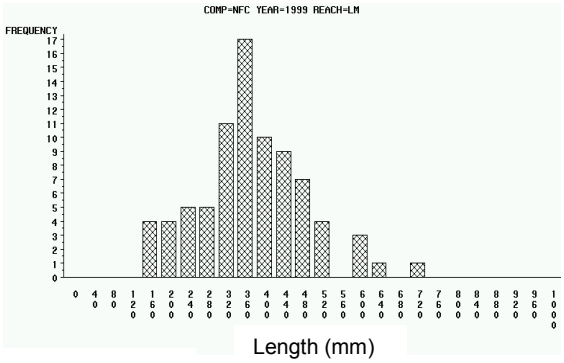


2000

Figure A.2: Length frequency histograms for Murray cod caught from Lake Mulwala at the Mulwala Classic, 1993-2000.



1995



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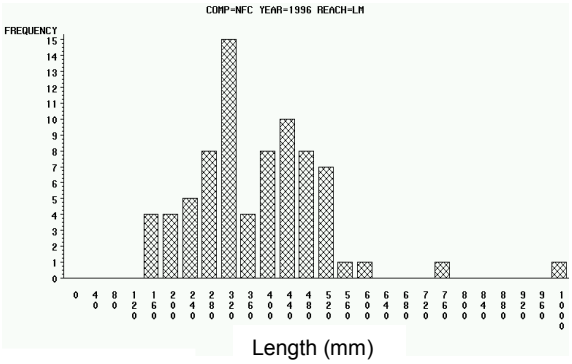

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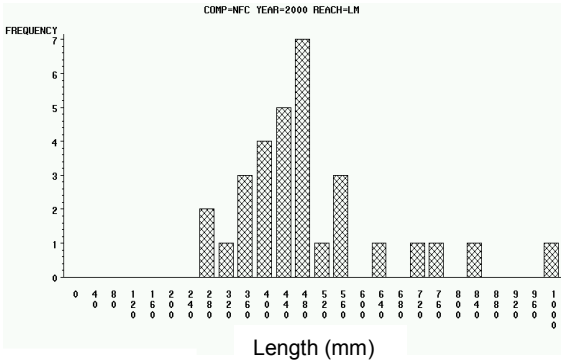

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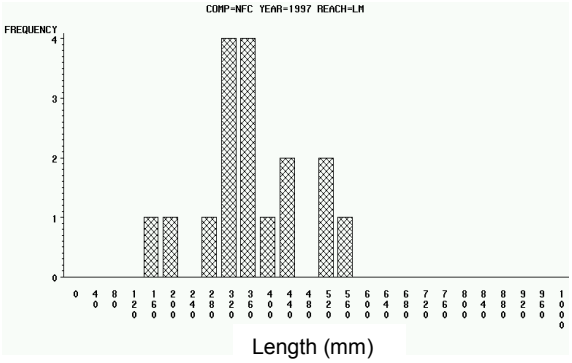
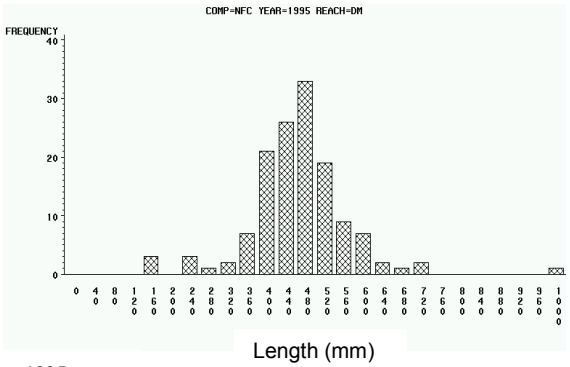
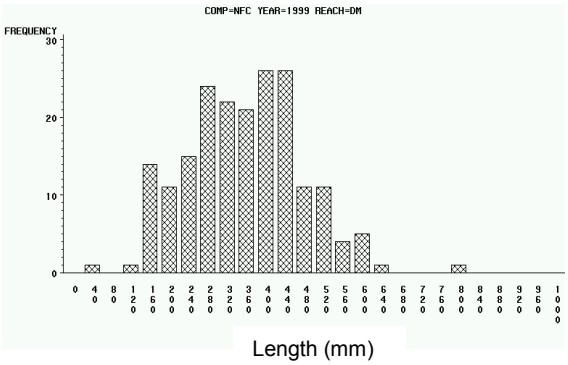


1997

Figure A.3: Length frequency histograms for Murray cod caught from Lake Mulwala at the Native Fish Challenge in 1995-1997 and 1999-2000.



1995



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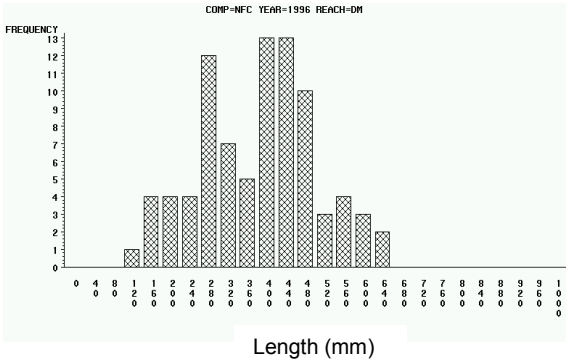

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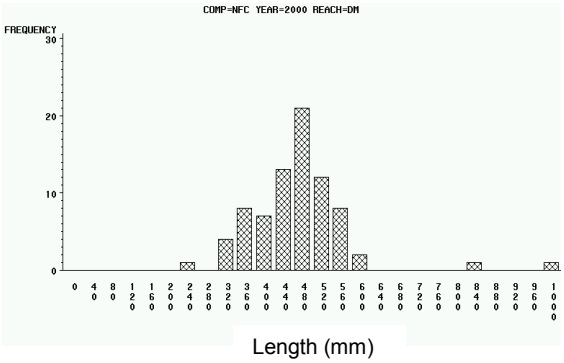

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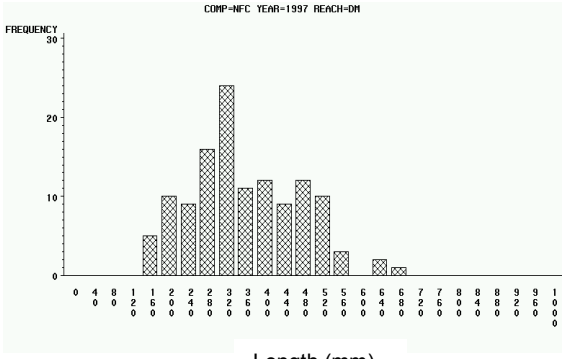

1997

Figure A.4: Length frequency histograms for Murray cod caught in the Lower Murray at the Native Fish Challenge in 1995-1997 and 1999-2000.

APPENDIX B:

Table B.1: Murray cod stocking in New South Wales through the matching (Government/private) dollar-for-dollar scheme for 2000/2001 stocking season (from NSW Fisheries).

Organisation	*Nearest town*	*Stocking location*	*River Basin*	*Number of Murray cod fingerlings stocked*	*Stocking date*
Balranald Ex Servicemen's Club	Euston	River Murray	Murray / Darling	3,030	25 February 2001
Balranald Ex Servicemen's Club	Balranald	Murrumbidgee River	Murray / Darling	6,060	25 February 2001
Barham DSMC Angling Club	Barham-Murrabit	River Murray (Barham Mill Bend, Barham Township, Snaggy Point, The Gardens, Henry Lane)	Murray / Darling	4,544	6 January 2001
Bidgee Fishing Classic Committee	Grong Grong	Murrumbidgee River below Berembid weir	Murrumbidgee	4,545	17 February 2001
Corowa Anglers Club	Corowa	Wagon Wheel Reserve, Collondina State Forest	River Murray	15,200	17 February 2001
Crown Fishing Club	Hay	Hay Weir Pool, Murrumbidgee River	Murray / Darling	12,120	17 February 2001
Deniliquin RSL Fishing Club	Deniliquin	Edwards River	Edwards River	10,000	6 January 2001
Echuca-Moama Sport Fishing Club Inc	Echuca	River Murray McEudy Area	River Murray	3,786	13 January 2001
Ganmain Anglers Club Inc	Ganmain	Upstream of Jowses Reserve	Murrumbidgee River	1,818	31December 2000
Gulgong Amateur Fishing Club	Gulgong & Mudgee	Burrendong Dam	Cudgegong River	7,574	11 January 2001
Gundagai Anglers Club	Gundagai	Morleys Creek	Murrumbidgee River	1,516	10 December 2000
Howlong Anglers Club Incorporated	Howlong	River Murray, Howlong	Murray / Darling	3,030	23 December 2000
Jindera Anglers Club	Albury	River Murray at 12 Mile Reserve	River Murray	3,636	23 December 2000
Kyalite Angling Club	Kyalite	Wakool River	Edward / Wakool	1,515	13 January 2001
Lavington Anglers Club	Talmalmo	River Murray, Dora Dora, Fernbank, Jingellic	River Murray	4,542	28 January 2001
Mathoura Picnic Point Fishing Classic Committee	Mathoura	River Murray	River Murray	4,849	5 January 2001

Organisation	*Nearest town*	*Stocking location*	*River Basin*	*Number of Murray cod fingerlings stocked*	*Stocking date*
Moulamein Angling Club	Moulamein	Edward River	Murray / Darling	2,425	20 January 2001
Red Cliffs Apex Club	Red Cliffs	River Murray Karadoc Sandbar	Murray / Darling	900	28 January 2001
Tocumwal Angling Club	Tocumwal	Downstream of Tocumwal Road Bridge	River Murray	4,545	28 January 2001
Tolland Hotel Anglers Club	Wagga Wagga	Murrumbidgee River Wagga Wagga, Currawarna / Collingullie Road Bridge	Murrumbidgee River	2,426	1 January 2001
Tooleybuc and Piangil District Fishing Club	Tooleybuc	River Murray	River Murray	6,060	25 February 2001
Transgrid Freshwater Fishing Club				1,818	10 January 2001
Tumut Acclimatisation Society	Tumut	Blowering Dam	Tumut River	6,818	9 December 2000
Wakool & District Restocking Group	Wakool	Wakool River	Edward / Wakool	908	6 January 2001
Wellington Courthouse Hotel Fishing Club	Wellington	Macquarie River / Geurie	Macquarie	4,250	11 January 2001
Whitton Social Anglers Club	Whitton	Tim's Beach, downstream of Gogeldrie weir	Murrumbidgee	1,550	7 January 2001
William Farrer Hotel Fishing Club	Wagga Wagga	Murrumbidgee River Wagga Wagga	Murrumbidgee		
Yanco Hotel Social Anglers	Yanco	Between Yanco weir and Gogeldrie weir, Nandirong Beach	Murray / Darling	1,515	31 December 2000
Young District Anglers Association	Cowra	Wyangala Dam	Lachlan	3,030	4 February 2001
Mathoura Chamber of Commerce & Citizens	Mathoura	Gulpha Creek	River Murray	1,273	5 January 2001
Narromine Shire Council	Narromine	Macquarie River downstream of Narromine	Macquarie	3,636	7 December 2000
Warren Shire Council	Warren	Macquarie River upstream of Warren	Macquarie	3,636	7 December 2000
Total				***132,555***	

Note: It is predicted that a further 80,000 fingerlings will be stocked before the end of 2000/2001.

ANNOTATED BIBLIOGRAPHY

- ASFB Inc. (2000). Australian Society for Fish Biology Inc. Newsletter 30(2).

In this issue, the "Threatened Fishes Committee Report" is presented. It describes the conservation status of Australian fishes using both the Australian Society for Fish Biology and IUCN classification schemes. An explanation of each of the schemes is also provided.

- Berra, T.M. & Weatherley, A.H. (1972). A Systematic Study of the Australian Freshwater Serranid Fish Genus *Maccullochella*. *Copeia* **1972**, 53-64.

This paper rationalises the recognition of two species, Murray cod and trout cod, in the genus *Maccullochella*. A number of physical attributes of the two species are highlighted as reasons for the distinction between them, and it is recommended that the correct name for Murray cod is *M. peeli* (Mitchell, 1838) and that the trout cod be referred to as *M. macquariensis* (C & V, 1829).

- Cadwallader, P.L. (1986). Fish of the Murray-Darling system. In "The ecology of river systems", B.R. Davies and K.F. Walker (Ed's), pp. 679-94 (Junk: Dordrecht).

Many accounts have been written on fish of the Murray-Darling system, and of their life histories, distributions and commercial and recreational value. This chapter reviews the reproductive adaptations of those fish whose life cycles are completed entirely within the river system. It also discusses the effects of man on these species, and presents a case study of the distribution of native and introduced fish in a small, southern tributary.

- Cadwallader, P.L. & Backhouse, G.N. (1983). A Guide to the Freshwater Fish of Victoria, pp. 101-4. Victorian Government Printing Office, Melbourne, Victoria, Australia.

The identification of 50 or so species of fish likely to be found in the fresh or inland waters of Victoria is facilitated through the provision of descriptions of distinguishing features, distribution and abundance, habitat and biological notes. A brief description of the inland waters of Victoria, as well as the effects of man on the native fish fauna are also given.

- Cadwallader, P.L. & Gooley, G.J. (1984). Past and present distributions and translocations of Murray cod *Maccullochella peeli* and trout cod *M. macquariensis* (Pisces: Percichthyidae) in Victoria. *Proceedings of the Royal Society of Victoria* **96(1)**, 33-43.

Details of past and present distributions and translocations of Murray cod and trout cod in Victoria are presented. The information shows that Murray cod have only undergone a marginal reduction in their natural geographical range, but have declined markedly in abundance. In contrast, trout cod have declined in both abundance and distribution. This paper suggests that management actions incorporate stocking of hatchery-bred fish with active habitat management in selected areas.

- Cockshell, J. (1994). A River Murray viewpoint. *Southern Fisheries* **2(1)**, 10-13.

This review describes the views of a fishing retail shop owner who relates the issues and views of users of the River Murray. The major area of concern, the confusing differences between the 3 states through which the river flows as regards to fishery regulations, is highlighted. In addition the lively controversy caused by the lifted ban on the taking of the native Murray cod is described, as is the issue of ownership and management of fishing reaches within the river system.

- Davis, K.M., Kearney, R.E. & Beggs, K.E. (2000). Research Priorities for Australia's Freshwater Fisheries. *Australian Journal of Environmental Management* **7**, 28-37.

The coordination of Australia's freshwater fisheries management is limited, and major issues affecting the sustainability of freshwater fisheries are influenced by water and land management agencies other than those with specific responsibility for fisheries. In response to these problems, this article identifies and prioritises the six major threats to the sustainability of Australia's freshwater fisheries resources. The results are based on information gathered from one survey and two expert panels.

- DNRE (unpublished). Bringing native fish back to the rivers – Tools for survival.

This information pamphlet provides a historical account of the perceived abundance of Murray cod at the time of European settlement. It also described a project that is developing PC-based decision support software with which managers can model a series of management scenarios for a range of Murray-Darling Basin fish species.

- Douglas, J.W., Gooley, G.J., Ingram, B.A., Murray, N.D. & Brown, L.D. (1995). Natural hybridisation between Murray cod, *Maccullochella peelii peelii* (Mitchell) and trout cod, *Maccullochella macquariensis* (Cuvier) (Percichthyidae) in the River Murray, Australia. *Marine and Freshwater Research* **46(4)**, 729-734.

This paper confirms that hybridisation has occurred between two wild, naturally sympatric populations of Murray cod and trout cod from the River Murray. Electrophoretic comparisons of proteins in muscle and liver tissue from trout cod, Murray cod, an artificially produced hybrid and putative wild hybrids showed that the latter group were first-generation interspecific hybrids. Although this is the first record of hybridisation between naturally occurring populations of the two species, naturally occurring wild populations of these species are genetically distinct and there is no evidence of introgression between them. The paper highlights implications for management policies and practices arising from this issue.

- Environment Australia (2000). Biodiversity Research: Australia's Priorities – A Discussion Paper.

The need to identify biodiversity research priorities was identified as a priority action in The National Strategy for the Conservation of Australia's Biodiversity. In response to this, a "National Biodiversity Research Priorities Strategic Planning Workshop" was held to draw advice from key areas. The Biological Diversity Advisory Council then reported on the advice received through this workshop. This discussion paper is

based on that report. The framework for considering biodiversity research priorities is through a series of questions relating to the occurrence, value, function and changes to Australia's biodiversity.

- Faragher, R.A. & Harris, J.H. (1994). The Historical and Current Status of Freshwater Fish in New South Wales. *Australian Zoologist* **29(3-4)**, 166-175.

Examples are given of a number of New South Wales freshwater fish species, including Murray cod, which have declined in abundance since last century. Potential causes of these declines are presented, along with possible remedial measures to restore both habitat and fish communities.

- Forster, A. (2000). Murray cod Aquaculture: an industry in the making?: Proceedings of a workshop held 18 January, 2000, Eildon, Victoria. VDNRE, Melbourne, Victoria, pp. 1-3.

This presentation describes how the farming attributes of Murray cod have been recognised since the 1980's, but that it is only recently that intensive aquaculture of Murray cod has prospered. Recent development has mostly come about because of the establishment and application of modern farming facilities, which have provided efficient, intensive and controlled farming conditions, under which Murray cod have thrived. While Murray cod currently has a reasonable degree of product awareness in Australia, the author suggests that the timing is right to invest in strategic market development for the entire industry.

- Gehrke, P. (1994). Effects of flooding on native fish and water quality in the Murrumbidgee River. In "The Murrumbidgee, Past and Present", J. Roberts and R. Oliver (Ed's), pp. 60-67 (NSW Fisheries).

In this chapter, the role of floods in fish production is described. The flood-recruitment model is presented, as is the effect of water quality on behaviour of larval fish. In addition, problems for fish in flooded habitats, and the implications of these issues for fish recruitment, are outlined. This chapter provides some useful information on the spawning requirements of Murray cod, as well as threats to Murray cod, both natural and human induced.

- Gehrke, P. (2000). 2000 Freshwater Fish Report. NSW Fisheries Annual Research Report 2000.

The ecological significance of fish in freshwater ecosystems is explained in this report, along with the current status of biodiversity of fish species in New South Wales river systems. Processes that are threatening biodiversity are described, as is current management practices and recent NSW Fisheries research. In addition, recommendations for future research are made. This general introduction is then followed by summaries of research projects currently being conducted by NSW Fisheries.

- Gehrke, P.C. & Harris, J. (2000). Fish in the Darling River System. In "The Darling River". Murray-Darling Basin Commission, Canberra (in press).

This publication discusses the three general river types that together, make up the Darling River system. They are: 1) montane rivers which lie at elevations greater than 700m above sea level, 2) slopes rivers between 700m and 300m above sea level, and 3) lowland rivers below 300m. The report then refers to these three main river types to explain fish abundance and distribution, both in a historical and contemporary perspective. Declining species and causes of decline are discussed with Murray cod being mentioned relatively frequently. In addition, the importance of fish in general, and Murray cod in particular, are discussed with reference to both Aboriginal and European values. Parts of this literature are quite relevant to the status of Murray cod in the Murray-Darling Basin.

- Gooley, G.J., Anderson, T.A. & Appleford, P. (1995). Aspects of the reproductive cycle and gonadal development of Murray cod, *Maccullochella peelii peelii* (Mitchell) (Percichthyidae), in Lake Charlegrark and adjacent farm ponds, Victoria, Australia. *Marine and Freshwater Research* **46**, 723-8.

The gonadal development of Murray cod in Lake Charlegrark, Victoria and adjacent farm ponds is evaluated. Gonadosomatic index, macroscopic classification and histological analysis are used to determine the age at first maturity and the gonadal development of this introduced population.

- Hamlyn, A. & Holloway, M. (1998). Post stocking survey report, Lake Leslie, Warwick, survey 4. Queensland Department of Primary Industries, Brisbane, Queensland, Australia, 22 pp.

This report gives the results of a post stocking survey conducted at Leslie Dam, Warwick, Queensland. The purposes of the survey were: 1) to determine the status of the freshwater jew population, 2) to determine the status of the Murray cod population, and to determine if recruitment had recently occurred, 3) to measure the relative abundance of angling, 4) to measure the relative abundance and species composition of forage and non-angling species, and 5) to review and provide recommendations on management species for the fishery. Results for electrofishing, netting and trapping used in the survey are given. In addition, length-weight data is appended.

- Harris, J.H. (1995). The use of fish in ecological assessments. *Australian Journal of Ecology* **20(1)**, 65-80.

The suitability of fish as a tool for assessing aquatic environments is discussed. While fish have been used in many different roles for assessing river health and monitoring responses to remedial management, three applications are of particular value for management of Australian rivers. These are discussed, with particular reference to the Index of Biotic Integrity (IBI). A provisional structure is suggested for a test of the IBI in four riverine regions of New South Wales.

- Harris, J.H. & Gehrke, P. (1997). Fish and Rivers in Stress: The NSW Rivers Survey. 298 pp. NSW Fisheries Office of Conservation and the Cooperative Research Centre for Freshwater Ecology, Cronulla, NSW, Australia.

The NSW Rivers Survey was designed around five specific objectives. These were to: 1) study the distribution, diversity and abundance of the native fish of NSW rivers, 2) determine the abundance, distribution and habitat use of carp and other alien species in NSW rivers, 3) develop understanding of the ecological effects of river regulation, 4) establish and test a standardised predictive model for monitoring river health using fish community assessment, and 5) establish a standardised survey structure for use in other studies.

- Harris, J.H. & Rowland, S.J. (1996). Family Percichthyidae - Australian freshwater cods and basses. In "Freshwater Fishes of South-eastern Australia". R.M. McDowall (Ed.), pp. 150-163, Reed, Sydney, Australia.

The family Percichthyidae is described. In addition, each species within this family in described in terms of its physical appearance, distribution, conservation status and natural history. A key to the identification of cods and basses is also provided.

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

This paper challenges the theory of the importance of flooding and the flood plain in the life cycles of Murray-Darling fishes. The significance of in-channel habitat has traditionally received little attention, despite the lack of evidence that temporary flood-plain habitats are utilised by larvae, juveniles or adults. The paper uses the "low flow recruitment hypothesis" to attempt to explain why some species spawn during the warmest months and lowest flows and how they are able to recruit under these conditions.

- Hundloe, T. (1997). Report to the Victorian Fisheries Co-Management Council on the Allocation of Fish Between Commercial and Recreational Fishers. 32 pp. Victorian Fisheries Co-Management Council, Melbourne.

The relative values of allocating the fish resources of Victoria's bays and inlets to recreational and commercial uses are analysed and debated. Data are derived from commercial fisheries catch returns, market prices and contingent valuation of the marginal value of fish to recreational fisheries. It is stressed that assessment value must not be based on expenditure.

- Ingram, B.A. (2000). Murray cod Aquaculture, a Potential Industry for the New Millennium: Proceedings of a workshop held 18 January, 2000, Eildon, Victoria. VDNRE, Melbourne, Victoria, 43 pp.

Aquaculture of Murray cod has enabled the production of hundreds of thousands of Murray cod fingerlings. However, both producers and markets have recently expressed considerable interest in the grow-out of Murray cod to satisfy a significant domestic and export demand for human consumption. The workshop discussed in these proceedings aimed to: 1) present result from recent developments in Murray cod

aquaculture, 2) introduce a three year project investigating Murray cod aquaculture, 3) initiate steps toward collaborative industry-focused research and development, and 4) update the network of people interested in the aquaculture of Murray cod. In this issue, abstracts of papers selected from those presented at the workshop are cited.

- Ingram, B.A., Larkin, B. (2000). Murray cod Aquaculture: current information and current status: Proceedings of a workshop held 18 January, 2000, Eildon, Victoria. VDNRE, Melbourne, Victoria, pp. 4-16.

This presentation discusses the techniques that have been developed over the last 10-15 years for the routine and relatively large-scale hatchery production of Murray cod. It notes that this technology is largely limited to the seasonal production of fry and small fingerlings of 15-30mm, 0.1-1.5g. It then discusses the fact that the State Governments in Victoria and New South Wales have allowed stocking of Murray cod in both public and private waterways for recreational and conservation purposes.

- Interim Report of the Select Committee on the River Murray, July 2000 – Third Session, Forty-Ninth Parliament.

This report is not particularly related to the status of Murray cod in the Murray-Darling Basin. Rather, it focuses on the current state of the River Murray, and the importance of this resource to South Australia. The report presents evidence on natural resource issues gathered from both a Basin-wide and state level. These issues include salinity, the Cap, institutional arrangements, water use, environmental flows, wetland and fisheries management, community involvement, land use change and investment. No recommendations are made in the report, as the Select Committee recognises that its investigations are incomplete, and it would be futile to make any definitive recommendations at this stage.

- Jackson, P.D. (1992). Freshwater Habitat Protection-A manager's perspective. Australian Society for Fish Biology Workshop, Victor Harbour, SA, 12-13 August, 1992.

Habitat degradation has been implicated in the decline of many native fish species. The Freshwater Fish Action Plan lists habitat degradation along with negative interactions with introduced species as the major threatening processes for freshwater fishes. This paper examines the protection of fish habitat from a manager's perspective and uses the plight of the Mary River cod to illustrate some of the points.

- Kailola, P.J., Williams, M.J., Stewart, P.C., Russell, E.R., McNee, A. & Grieve, C. (1993). Australian Fisheries Resources. Bureau of Resource Sciences and the Fisheries Research and Development Corporation, Canberra, Australia, pp. 266-268.

This book mainly focuses on fisheries resources although it also contains information on the Australian fishing industry, fishing gear and the environment. It contains a section on Murray cod describing its distribution, life history and stock structure. In addition, information on both the commercial and recreational fishery is given, along with the Murray cod resource status.

- Kearney, B. (1999a). Evaluating Recreational Fishing: Managing perceptions and/or reality - Evaluating the Benefits of Recreational Fisheries. *Fisheries Centre Research Reports* **7(2)**, 9-14.

This article discusses the role of politics in fisheries management, particularly in regard to the recreational fishery. The difficulty of evaluating this fishery is discussed, and key parties with an interest in recreational fisheries management are outlined.

- Kearney, B. (1999b). Perspectives on Evaluating Recreational Fisheries from the Keynote Speakers - Evaluating the Benefits of Recreational Fisheries. *Fisheries Centre Research Reports* **7(2)**, 44-45.

Here, the views of the author on what he felt was achieved at the conference, and what was not achieved, on the subject of evaluating the benefits of recreational fishing are presented. The author felt that more emphasis needs to be given to property rights and access rights in the management of recreational fisheries. The potential for the animal rights movement to target the catch-and-release fishery is also discussed.

- Kearney, R.E. (2001). Fisheries property rights and recreational/commercial conflict: implications of policy developments in Australia and New Zealand. Marine Policy. Elsevier Science Ltd.

Increased conflict between the recreational and commercial fishing sectors is occurring, and is changing from physical competition for fish to economic and legal arguments over social priorities. This article investigates the advantages and disadvantages of increased use of property rights in resource allocation, and argues that the recreational sector requires better definition of its claim for priority access to resources.

- Kearney, R.E., Davis, K.M. & Beggs, K.E. (1999). Issues affecting the sustainability of Australia's freshwater fisheries resources and identification of research strategies. Project No. 97/142.

This project identifies the six major threats to Australia's freshwater fisheries resources. These are examined in detail to: 1) determine the primary causes for these threats, 2) assess which threats could be approached by a national or State by State cooperative strategy for research, and 3) to propose a strategy for coordinating and funding new research relevant to ensuring the sustainability of Australia's freshwater fisheries resources.

- Koehn, J. (1994). The Cod Story. Conference: The Geomorphology and Biology of Streams, December 5th, 1994.

This report gives the results of four studies conducted by the Freshwater Ecology Section of the Department of Conservation and Natural Resources. These are: 1) the Murray cod radio tracking project, 2) Young-of-the-year Murray cod habitat preferences, 3) Trout cod biology, and 4) Mitta Mitta River post Dartmouth Dam fish surveys.

- Koehn, J. (1996a). Habitats and movements of freshwater fish in the Murray-Darling Basin. In proc. 1995 Riverine Environment Research Forum (Ed's. R.J. Banens and R. Lehane) pp. 27-37. October 1995. Attwood Victoria. Publ. Murray-Darling Basin Commission.

This paper describes two studies that were jointly funded by the Murray Darling Basin Commission and the Victorian Department of Conservation and Natural Resources. The first, the "Cod Radio-tracking Project", was conducted from July 1992 to July 1995. It developed radio-tracking technology, which enabled study to be completed on the basic ecology of Murray cod. Elements of this study then led to the second project on "Habitat and Movement Requirements of Fish". This study highlighted the effect of desnagging, flow regulation and barriers to Murray cod populations.

- Koehn, J.D. (1996b). The key criteria to sustaining the wild stock Murray cod fishery in Lake Mulwala. In: Hancock, D.A. and Beumer, J.P. (ed's) Proceedings of the Second World Fisheries Congress (Volume 1) Developing and Sustaining World Fisheries Resources: The State of Science and Management. Brisbane, July 1996.

This abstract, focuses on Lake Mulwala and its role in the ecology of Murray cod. It states that spawning fish move out of the lake and up into the rivers to spawn, and then return to their original position in the lake. Cod larvae have been shown to drift downstream from the rivers, and then settle in the still water of the lake. The lake provides suitable habitat for both large and small Murray cod, and also provides an abundant food supply for juvenile Murray cod. For this reason, it is believed that Lake Mulwala fills the role of a nursery ground for this species, a view supported by the younger population structure present in the lake compared to that of the rivers. It was concluded that there is an important relationship between the lake and the rivers in maintaining the Murray cod fishery, and that the two should, therefore, be managed together in order to maximise production.

- Koehn, J., Doeg, T., Harrington, D. & Milledge, G. (1995). Dartmouth Dam: Effects on the downstream aquatic fauna. 1995 Riverine Environment Research Forum. Murray Darling Basin Commission.

Impoundments and their operation have been widely implicated in the decline of most Australian native freshwater fish species. Particular concern has been expressed over the downstream impact of the water from the thermally stratified Lake Dartmouth. This study aimed to: 1) determine any changes to the fish and aquatic macro-invertebrate fauna of the Mitta Mitta River following the construction and operation of Dartmouth Dam, 2) estimate the magnitude of these changes and assess their importance and impact, 3) determine the major reasons for the changes, 4) suggest future management actions, and 5) provide baseline data for any post-remediation studies.

- Koehn, J. & Nicol, S. (1998). Habitat and movement requirements of fish. In proc. 1996 Riverine Environment Forum (Ed's. R.J. Banens & R. Lehane) pp. 1-6. October 1996, Brisbane, Queensland. Publ. Murray Darling Basin Commission.

The project described in this paper aims to determine the habitat and movement requirements of Murray cod and other native freshwater fish species. The study was conducted in the River Murray, downstream of Yarrawonga, with some additional work in Lake Mulwala and the Ovens River. Many of the results presented in this paper were preliminary at the time of publication, with further data collection and analysis in progress. The paper does however, describe the preferred habitat and habitat features required by the Murray cod. It also examined the movement of Murray cod in the River Murray and the Ovens River. Some management implications of these findings are presented.

- Lake, J.S. (1967). Principle fishes of the Murray-Darling river system. In "Australian Inland Waters and their Fauna". A. H. Weatherley (Ed.), pp. 192-213. Australian University Press.

This chapter described the Murray-Darling system, and the principal fish species of this system. Topics discussed include breeding stimuli, effects of environmental changes, temperature tolerances and the fish themselves. A physical description is given of Murray cod, as well as a description of the reproductive regime of this species.

- Larkin, B. & Ingram, B.A. (2000). Murray cod: overview of recent industry developments: Proceedings of a workshop held 18 January, 2000, Eildon, Victoria. VDNRE, Melbourne, Victoria, pp. 17-25.

Data on current world consumption of seafood, and information on the role of aquaculture in filling the demand for seafood is given. The presentation states that products from aquaculture for human consumption in Australia must be targeted at the high-middle to top end of the market, as production and labour costs are too high to compete in a world market with nations producing fish as a cheap source of protein. Analysis of historical price and volume data for particular fish species suggests that Murray cod has a potential for aquaculture, and that it is in the higher price bracket for finfish in Australia. This presentation also outlines some of the problems and issues encountered by Murray cod farmers, as well as information about permits and licenses, finances, labour, training, contacts and useful websites.

- Mallen-Cooper, M. (1992). Habitat changes and declines of freshwater fish in Australia: What is the evidence and do we need more? Australian Society for Fish Biology Workshop, Victor Harbour, SA, 12-13 August, 1992.

The published evidence for the decline in range and abundance of freshwater fish species over the last 100 years is examined. In addition, the habitat changes, which are implicated with these declines, are examined, as is the quality of the evidence linking the two.

- Morris, S.A., Pollard, D.A., Gehrke, P.C. & Pogonoski, J.J. (2000). Threatened Freshwater Fishes of Coastal New South Wales and the Murray-Darling Basin (Draft). Report to the World Wide Fund for Nature and Fisheries Action Program by NSW Fisheries Office of Conservation.

This report reviews the general characteristics and conservation status of twenty-nine species of threatened and potentially threatened freshwater fishes inhabiting the rivers and streams of the Murray-Darling Basin and coastal New South Wales. The report draws together information from discussions at a workshop aimed at discussing the proposed conservation status of as many of the identified species as possible, and at reaching a consensus on the conservation status for each species. Some causes of the decline in freshwater fishes are outlined. It is hoped that this report will provide the impetus for more research into threatened freshwater fishes of the Murray-Darling Basin and coastal river systems of New South Wales. This report provides some excellent information on the current conservation listing of Murray cod, as well as suggestions of what these listings should be.

- Mosig, J. (2001). Conservation Genetics Inventory Project. *Austasia Aquaculture*, December 2000/January 2001, 46-47.

This paper is derived from a project with the working title "Conservation genetics of Trout cod, Murray cod and Silver perch". The paper is basically a commentary on the above project, with comments from various researchers. The issue of genetic diversity of hatchery reared native fish, and implications of the release of these fish in the wild are discussed. It also outlines some guidelines relating to the release of hatchery reared native fish to ensure that genetic diversity in the wild is not reduced, and to ensure that populations remain reproductively viable. This paper is quite useful for discussing the potential problems of viewing artificial stocking of Murray cod as a solution to the decline of distribution and abundance of this species.

- O'Bara, C.J. (1999). Economic benefits and value of a localised and seasonal Walleye fishery - Evaluating the Benefits of Recreational Fisheries. *Fisheries Centre Research Reports* **7(2)**, 124-129.

The characteristics of a seasonal river walleye fishery during an eight-week period in 1995, 1996 and 1997 are described. The cost for anglers, and angling effort, during the season was calculated. It was found that total economic output for the eight-week fishery exceeded $740,000 per season. This economic value was heightened when the geographic setting was considered, since the location of the fishery was in an isolated county with an economy based primarily in outdoor recreation. Communication of economic value information is a primary aspect of this study, and examples in several arenas are presented.

- Pierce, B.E. & Doonan, A.M. (1999). A summary report on the status of selected species in the River Murray and lakes and Coorong fisheries. South Australian Fisheries Assessment Series 99/1. 14pp.

Cited in Ye *et. al*., 2000.

- Pitcher, T.J. (1999). Director's Forward – Evaluating the Benefits of Recreational Fisheries. *Fisheries Centre Research Reports* **7(2)**, 5-8.

This article gives a historical account of recreational fishing, which dates back as far as human civilisation itself. The perceived benefits of recreational fishing are outlined, as well as the difficulties of evaluating these benefits. The objectives of the conference from which the Fisheries Centre Research Report was derived, are also outlined.

- Reid, D.D., Harris, J.H. & Chapman, D.J. (1997). NSW Inland Commercial Fishery Data Analysis. FRDC Project No. 94/027, December.

This report is particularly useful to the current project. The report presents catch data from the Inland Commercial Fishery, collected since 1947. A number of errors in previous data sets were identified and corrected in the report, and summaries are given for the catch, effort and catch-per-unit-effort over the period 1947/48 to 1995/96. While the information collected from commercial fishers provides reliable estimates of the total catch and trends in CPUE by species, the data are not adequate for the application of age-based stock assessment techniques. The report also points out that, even with complete information from the commercial fishery, the fishery itself is extremely limited geographically. Therefore, the status of a stock in the commercial fishery may not necessarily reflect the stock status over the entire Murray-Darling river system. This report also confirms a strong correlation between time series of river levels or flows, and catches of Murray cod.

- Reynolds, L.F. (1984). Migration patterns of five fish species in the Murray-Darling river system. *Australian Journal of Marine and Freshwater Research* **34(6)**, 857-871.

This study showed that the migration pattern of Murray cod appeared to be similar to that of European carp. That is, they did not migrate, but rather made only random, short distance movements. Since this result indicated that Murray cod are relatively sedentary, it was postulated that purely local events such as over-fishing, pollution, destruction of spawning areas by river channelisation and desnagging could seriously depress or even destroy local populations.

- Rohan, G. (1989). River Murray fishery review. *SAFISH* **13(3)**, 4-7.

A review is presented on the commercial fisheries of the River Murray in South Australia and changes which have occurred over the past few years resulting in the need for a change in management arrangements. Research information and public comment concluded that stocks of native fish, including Murray cod, have declined as a result of environmental changes to levels which can no longer sustain the fishing effort they once did.

- Rowland, S.J. (1983). Spawning of the Australian freshwater fish Murray cod, *Maccullochella peeli* (Mitchell), in earthen ponds. *Journal of Fish Biology* **23**, 525-534.

This paper describes the cues required for Murray cod to spawn in earthen ponds. It states that spawning was induced when the water temperature rose to or above 20°C,

and that a corresponding rise in water level was not needed. However, it was suggested that Murray cod larvae need a significant rise in water levels to coincide with the breeding season, to ensure a high level of survival.

- Rowland, S. (1988). Murray cod. *NSW Agriculture and Fisheries*, Agfact **F3.2.4** 10pp.

This publication gives an excellent history of the Murray cod in the Murray-Darling Basin. It summarises the distribution of Murray cod, both natural and stocked populations, as well as the preferred habitat features of Murray cod. It also describes the pattern of decline of Murray cod numbers, and presents some reasons for this decline. The biology of Murray cod is also investigated, and a summary of the commercial and recreational Murray cod fishery is given, including methods of capture. This publication also described methods of artificial propagation of Murray cod that have been successfully used to produce Murray cod for stocking in public waters in New South Wales.

- Rowland, S.J. (1989). Aspects of the History and Fishery of the Murray Cod, *Maccullochella peeli* (Mitchell)(Percichthyidae). *Proceedings of the Linnaean Society of New South Wales*, **111(3)**: 201-213.

This paper provides an excellent summary of the history of the Murray cod. It briefly reviews the part played by Murray cod in Aboriginal mythology and culture, the observations made of the species by explorers and early settlers, and the development, decline and current status of the Murray cod fisheries. In addition, possible causes of the decline in abundance and distribution of Murray cod are discussed.

- Rowland, S.J. (1995a). Aspects of the reproductive biology and hatchery production of Murray cod, golden perch and silver perch from the Murray-Darling river system. Translocation Issues in Western Australia: Proceedings of a seminar and workshop held on 26-27 September, 1994, pp. 38-49, Fisheries Management Paper, Fisheries Department of Western Australia, vol. 83.

This paper gives some information on the reproductive biology of Murray cod, golden perch and silver perch. It describes the conditions required for all three species to breed, spawn, and for eggs to hatch. It also notes that Murray cod spawn regularly in impoundment's and dams, although recruitment is generally poor. In contrast, golden perch and silver perch rarely spawn in impoundment's and farm dams, because their spawning is induced by a significant rise in water level when the temperature is over 20°C.

- Rowland, S.J. (1995b). Stocking of Freshwater Fishes and Policy in New South Wales. WA Fisheries Management Paper No. 83, Fisheries Department of Western Australia, pp. 50-61.

The dramatic changes to the original riverine environment of the Murray-Darling river system are considered to be major factors in the decline of a number of native freshwater fish species, including the Murray cod. Stocking of native fish is often used as a tool to combat declining abundance, and this paper presents data and

information on stockings of freshwater fish in New South Wales. In addition, potential detrimental effects of fish stocking are briefly discussed, and the key features of the NSW Fisheries stocking policy are outlined.

- Rowland, S.J. (1998a). Aspects of the Reproductive Biology of Murray Cod, *Maccullochella peelii peelii. Proc. Linn. Soc. N.S.W.*, **120**, 147-162.

In this paper, aspects of the reproductive biology of Murray cod in New South Wales tributaries of the Murray-Darling river system are described. It was found that Murray cod have a distinct seasonal cycle. The study showed that absolute fecundity ranged from 6800-86600 eggs, and that relative fecundity ranged from 3.2-7.6 eggs/g. Spawning was induced by a rise in water temperature to or above, 20°C in spring. The study also found that no females or males were mature by three years of age. At four years of age, 77% of females, and 72% of males were mature, and at five years of age, all females and most males were mature.

- Rowland, S.J. (1998b). Age and Growth of the Australian Freshwater Fish Murray Cod, *Maccullochella peelii peelii. Proc. Linn. Soc. N.S.W.*, **120**, 163-180.

The objectives of this study were to develop reliable ageing techniques that enable accurate assessment of age in Murray cod, to compare growth rates of Murray cod from different tributaries of the Murray-Darling river system, and to determine overall growth and length-weight relationships for the species. It was shown that checks are formed on both the opercular bones and the otoliths of most juvenile and adult Murray cod during October and November. Because Murray cod breed during these months, cod can be directly aged by counting checks. The study found that there was no significant difference between the growth or length-weight relationships of males and females, or cod from different tributaries. However, Murray cod from the impoundment Lake Mulwala, were significantly larger than same-aged cod from rivers. The study was also successful in determining an overall growth and length-weight relationship for Murray cod.

- Rowland, S.J. & Ingram, B.A. (1991). Diseases of Australian native freshwater fishes with particular emphasis on the ectoparasitic and fungal diseases of Murray cod (*Maccullochella peeli*), golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*). *Fisheries Bulletin* **4**, NSW Fisheries.

This bulletin discusses a number of pathogenic organisms that have been found on native freshwater fishes at the Inland Fisheries Research Station, Narrandera. The paper states that Murray cod are susceptible to chilodonelliasis, and that an epizootic of Chilodonella sp. was responsible for the mortality of 24% of Murray cod broodfish in ponds in one week in September 1980, just before the breeding season. The paper then rrecommends some actions that should be employed by culturists to reduce the incidence of diseases.

- Schiller, C.B., Bruce, A.M. & Gehrke, P.C. (1997). Distribution and abundance of native fish in New South Wales rivers In: Fish and Rivers in Stress – The NSW Rivers Survey, J.H. Harris & P.C. Gehrke (Ed's). NSW Fisheries Office of onservation and the Co-operative Research Centre for Freshwater Ecology, Cronulla, NSW. pp. 71-102.

The baseline information provided by the New South Wales Rivers Survey is vital for effective conservation and management of native fish populations in New South Wales. It facilitates identification of populations and species under threat of suffering ongoing reductions in distribution or abundance. It also acts as an aid in identifying and understanding threatening processes. This particular chapter provides a descriptive account of the distribution and abundance of native fish in New South Wales rivers as well as an assessment of the status of native fish resources in New South Wales.

- Stoney, K. (2000). Export market evaluation for Murray cod: Proceedings of a workshop held 18 January, 2000, Eildon, Victoria. VDNRE, Melbourne, Victoria, pp. 28-29.

This paper describes a "Market Taste Test Evaluation Project" that was conducted as a preliminary investigation to identify opportunities for Australian farmed Murray cod in overseas markets. Results showed that Australia was viewed as a preferable source of healthy, safe and high quality fish, and that the industry should consider promoting fish from a clean environment rather than as "farmed". While price is the most important factor in making Murray cod competitive with better known species, Murray cod was identified as suitable for both Chinese and Western cuisine.

- Ye, Q., Jones, K. & Pierce, B.E. (2000). Murray Cod (*Maccullochella peelii peelii*). Fishery Assessment Report to PIRSA for the Inland Waters Fishery Management Committee. South Australian Fisheries Assessment Series 2000/17.

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. The indicators are estimated from compulsory catch and effort data, or from information collected voluntarily by commercial fishers. This includes: 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.