Overview of the history, fishery, biology and aquaculture of Murray cod (Maccullochella peelii peelii)

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Abstract

Murray cod is endemic to the Murray-Darling River System and is *the fish* in the hearts and minds of inland Australians. Aboriginal mythology links Murray cod to the formation of the Murray River and other native fish, and it was a major food item and part of the culture of inland tribes. Like most other Australian freshwater fishes, Murray cod has a marine ancestry, with fossils of Miocene age. Explorers and early settlers were astounded by the abundance, size and delicacy of Murray cod with pioneers and early settlers relying on cod as a source of fresh food. From the 1860s, a large inland commercial fishery developed, based mainly on the Murray and Murrumbidgee rivers. There was a gradual decline from a peak in 1918, and by the mid 1930s the fishery had become unprofitable for large operators. Between the mid 1950s and 1960s, there was a dramatic decline in the total commercial catch and the catch per fisherman. The catch remained at a low level until the NSW fishery closed in 2001. Through the early and mid 1900s, there was also a reduction in the distribution of Murray cod, particularly above impoundments and in Victorian waters. It is suggested that the following were major factors contributing to the decline of Murray cod: (i) overfishing between the late 1800s and the 1930s; (ii) the use of toxic chemicals such as arsenic in the sheep industry in the early 1900s; (iii) predation by, and competition with introduced redfin (*Perca fluviatilis*) in the 1950s and 1960s; and (iv) reduced survival and recruitment of larvae and juveniles due to the effects of river regulation since the 1950s.

Murray cod is a large, long-lived species. Growth and reproduction vary between some populations. The overall reproductive strategy involves contributions from many year classes, a long generation period (4 – 6 years), a short spawning season (4 – 6 weeks), a complex breeding behaviour involving pairing of broodfish, spawning site selection, and paternal protection of the large (3 mm), adhesive eggs during a well-defined breeding season in spring when water temperatures are 16° – 20ºC. The presence of many consecutive year classes in most rivers suggests that Murray cod spawn and recruit annually irrespective of changes in water level; however, strong year-classes are formed only in rivers that are at or near flood levels during the breeding season.

Hatchery techniques for Murray cod were developed in the early 1980s, and Government and commercial hatcheries now produce around 1 million fingerlings annually for stock enhancement and commercial grow-out aquaculture. A commercial grow-out industry, involving pond culture and tank-based re-circulating systems is developing and currently produces around 100 tonnes annually.

Anecdotal information and fisheries data suggest there has been a recovery of Murray cod in some NSW waters over the last 5-10 years. Factors contributing to this may be: (i) recent years of good natural recruitment; (ii) protection of stocks through fishing regulations introduced in NSW in 1992 (closed season, bag limits, size limit); (iii) stocking of hatchery-reared fingerlings; (iv) lower numbers of redfin and carp (*Cyprinus carpio*); and (v) improved environmental conditions.

Introduction

The Murray cod (*Maccullochella peelii peelii*) (**Figure 1**) is an Australian native, warmwater fish found naturally thorough-out most of the Murray-Darling River System (**Figure 2**), with the exception of the headwaters of some tributaries in Victoria and southern NSW (Lake 1971; Cadwallader & Backhouse 1983; Merrick & Schmida 1984). It is a member of the family Percichthyidae, which includes the other cod species trout cod (*M. macquariensis*), eastern freshwater cod (*M. ikei*) and Mary River cod (*M. peelii mariensis*) (Harris & Rowland 1996). It is a striking looking fish, with at times spectacular colour patterns of pale to dark green reticulated mottling dorsally and laterally on a cream, olive or yellow-green background; in larger specimens appearance can be more speckled and green-grey (**Figure 1**).

Murray cod are found in habitats ranging from small, clear, rocky streams on the Tablelands to the turbid, slow-flowing rivers, creeks and lakes of the Western Plains (Rowland 1988a; Harris & Rowland 1996). Cod are generally found in or near relatively deep water, and show a distinct preference for habitats containing cover such as rocks, large wooden snags, smaller woody debris, under-cut banks and over-hanging vegetation (Rowland 1988a; Harris & Rowland 1996; Koehn 1996). Murray cod is the top predator of the Murray-Darling River system, and is well known for its opportunistic and at times voracious appetite and the consumption of unusual items. Common food items include fish, crustaceans and mussels; less common are water dragons, turtles, frogs, water birds such as ducks and grebes, and terrestrial animals such as mice and snakes; unusual items reported are kookaburras, possums, a crow with a jam tin on its head, a butcher's knife, golf balls and a margarine container; and commonly used baits besides fish and crustaceans have been bardie or wood grubs, earthworms, centipedes, hard-boiled eggs, galahs and other birds, rabbit, kangaroo and pig meat (Rowland 1988a).

Figure 2. The Murray-Darling River System

The Murray cod is Australia's and one of the world's largest wholly freshwater fish. A cod of 113.6 kg is reported to have been captured in the Barwon River near Walgett in 1902 (Rowland

Figure 1. Murray cod, Maccullochella peelii peelii (total length 1010 mm, weight 24 kg) (from Rowland, 1985)

1989). Although cod in excess of 50 kg are rarely caught these days, small numbers of cod between 20 and 40 kg are regularly taken by experienced fishers, particularly in the Murray, Edward, Murrumbidgee, Darling, Macquarie, Barwon and MacIntyre rivers, and in impoundments such as Lake Mulwala, Burrinjuck Dam, Copeton Dam and Glen Lyon Dam. The flesh of Murray cod is firm and white, has relatively few bones, keeps well, is moist and has a superb flavour. Its size and excellent edible qualities, make Murray cod a prized fish and it is undoubtedly the most sought-after fish in inland Australia.

Besides its unique biological features, there is an aura about Murray cod and it is often referred to as the *icon* of the Murray-Darling Basin. It has a special place in Aboriginal mythology and culture, and played an important role in the lives of early inland explorers, pioneers and settlers. Folk lore abounds with stories and tall tales of Murray cod. Bushmen explained the tree-like markings on the swim-bladder of cod by swearing that the fish takes a photograph of its birthplace and surroundings on the river bank (Whitley 1941). Earlier generations of Australians were intimately linked to the inland rivers through this fish (Sinclair 2000), and Murray cod still plays such a role. It is undoubtedly *the fish* in the hearts and minds of all Aboriginal and white inland Australians, and is an integral part of our culture.

This paper uses scientific data and anecdotal information to review aspects of the history, fishery, biology and aquaculture of Murray cod. Reasons for the decline of Murray cod are presented, and it is suggested that there has been a recovery of the species in some NSW waters over the last 5 – 10 years.

Aboriginal Mythology and Culture

Aborigines of the lower Murray and Murrumbidgee rivers used the name *ponde* (sometimes spelt *pondi* or *pondy*) for Murray cod, but those in the upper Murrumbidgee River called the river cod *mewuruk*, and the Aborigines in the Tumut region called the varieties of cod *bewuk* and *mungee* (Ramsay Smith 1930; Berndt 1940; Bennett 1834); the latter two names possibly referring to Murray cod and trout cod.

Another Aboriginal name for Murray cod, *goodoo*, is now regularly used by some fishers and journalists. In Aboriginal mythology, the Murray cod was responsible for the formation of the Murray River and its fish (Ramsay Smith 1930; Berndt 1940). According to legend, a huge *ponde* (Murray cod) burst forth from the depths of the earth at the source of the Murray River, which was then only a small stream of water trickling to the southern ocean. *Ponde* struggled along the narrow stream digging with its head and swinging its tail making the river deep and forming all the bends, billabongs and other features of the river. Nepelle, the Great Prophet, speared it at a site now known as Lake Alexandrina and with the help of the creative hero Ngurunderi, cut it into pieces and threw the fragments into the water, naming them *tarki* (golden perch, *Macquaria ambigua*), *tukkeri* (bony bream, *Nematalosa erebi*), *tinuwarre* (silver perch, *Bidyanus bidyanus*) and all the other native fishes of the river. When they had finished, they threw the remainder back and said 'You keep on being *ponde*'.

Murray cod was a major food item of tribes living adjacent to inland waters (Lawrence 1971; Tindale 1981). As with all animals and plants, Aborigines made a detailed study of inland fishes, in particular the Murray cod which was considered *the fish*. According to Aborigines 'there was none to compare with it in freshwater lake or river or in salt-water lake or sea' (Ramsay Smith 1930). There is evidence of the use of sophisticated fishing methods in the lower Darling River around 25,000 years ago (Balme 1983). The Aborigines were excellent fishers and amazed explorers and early settlers with their prowess using spears, nets, poisons and different types of traps made of brush fences, stones or hollow logs to capture fish (Bennett 1834; Ramsay Smith 1930; Tindale 1951, 1981; Lawrence 1971; Balme 1983).

Fossil Records

Most Australian freshwater fishes, including Murray cod are considered to have a relatively recent marine ancestry (Whitley 1959). MacDonald (1978) suggested that *Maccullochella* and *Macquaria* diverged from a common ancestor during a marine stage of their evolution and made separate colonisations of Australian freshwaters.

Hills (1946) recorded fossil Murray cod from diatomaceous earth in the Warrumbungle Mountain area and considered the remains to be no older than Pliocene (started 7 mya). However, Browne (1972) stated that the basalt overlaying these diatomaceous earths had been dated as Upper Miocene, and Taylor *et al*. (1980) reported Murray cod fossils from diatomite in the Cooma region to be Miocene age (26 – 7 mya). The diatom flora associated with these fossils is of the type found in Lower Tertiary basalts (Gill 1970) and so the ancestral *Maccullochella* may be up to 60 – 65 million years old.

Explorers and Early Settlers

Inland explorers, pioneers and early settlers were astounded by the abundance, size and delicacy of Murray cod, or as it was commonly known 'codfish' or 'river cod'. The explorer George Evans was the first white man to see cod in the Fish and Macquarie rivers, near the present site of Bathurst in 1813 (Stansbury & Phipps 1980; Millar undated). In 1817, John Oxley wrote of cod in the Lachlan River:

> 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 large 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. (Oxley 1820).

The holotype of Murray cod (which has since been lost) was collected from the Peel River, near the present site of Tamworth in NSW, by the explorer Major Thomas Mitchell (Mitchell 1838). There is an excellent drawing of this fish, dated 14th December 1831, in Major Mitchell's field book (**Figure 3**), and he named the fish *Gristes peelii* after the Peel River [*Gristes* was later replaced with *Oligorus* and then *Maccullochella* (Berra & Weatherley 1972)]. Mitchell also described and sketched other native fish, including catfish (*Tandanus tandanus*) and silver perch. Members of expeditions led by Oxley, Mitchell and Charles Sturt caught and ate Murray cod (Oxley 1820; Mitchell 1838; Sturt 1899).

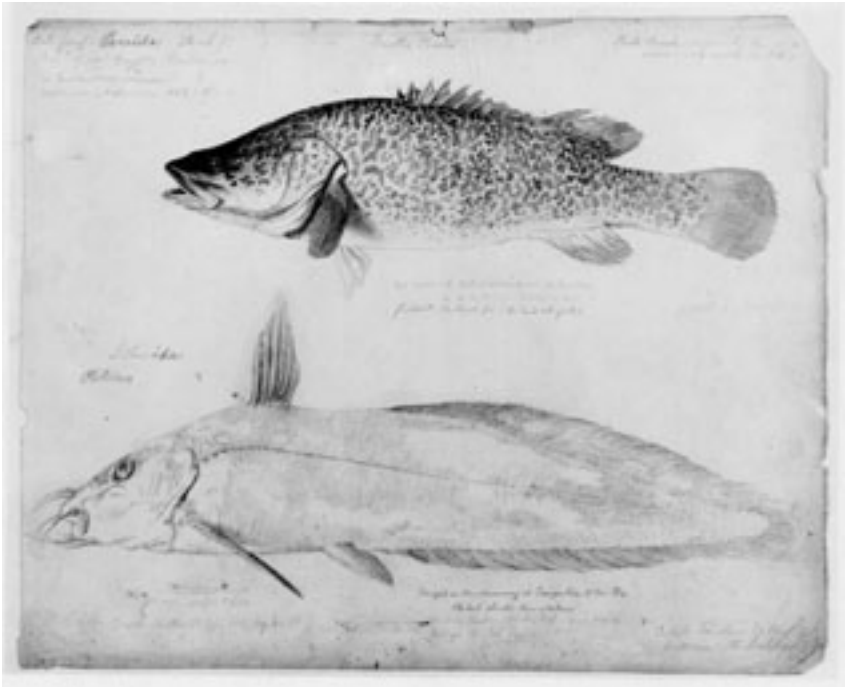

Figure 3. Drawings of a Murray cod and an eel-tail catfish in the explorer Major Thomas Mitchell's field book. Handwritten notes on the page state that the cod was caught in the Peel River on 14 December 1831 and named Gristes peelii (from Rowland, 1985)

Bennett (1834) wrote that large quantities of the delicious 'River Cod' weighing up to 120 lbs were caught in the Yas [sic] and Murrumbidgee rivers, and in 1863 he recommended to the Acclimatisation Society of NSW that every effort should be made to propagate them (Bennett 1864). Murray cod were held in such high esteem that the species was considered worthy of acclimatisation in England and Europe (Rowland 1989). Although this did not eventuate, Murray cod was stocked during the 19th century into many waters within Australia where it was not found naturally; the Yarra River (Victoria), the easterly-flowing Cox's, Nepean and Wollondilly rivers and Mulwarree Ponds of the Hawkesbury-Nepean catchment, and Lake George in NSW, the Mary River in Queensland, and the Avon River and Lake Grassmere in Western Australia (Rowland 1989). Apart from the occasional specimen from the Yarra River, cod are no longer found at these sites. During the 20th century, Murray cod were stocked in numerous other sites including Lake Bathurst, Lake Charlegrark, Green Lake, Taylor's Lake and the Wimmera River in Victoria, Cataract Dam and several other of Sydney's water supply dams and many farm dams through-out eastern Australia (Rowland 1989).

Murray Cod Fishery

Aboriginal fishery

The first Europeans in the Darling River region recorded that the Aborigines were aware of the effectiveness of various fishing techniques (Balme 1983). At times Aborigines specifically targeted Murray cod. Tindale (1951) described how Aborigines would dive up to 10 to 15 feet underwater from a canoe, place a hooped net over the entrance to a cavity or hole where cod had spawned eggs, make a splashing noise, catch the disturbed cod in the net and rise to the surface where another Aborigine in the canoe would spear the fish. Even in the late 1900s, some Aborigines have the ability to catch Murray cod and other native fish when they can't be caught by white Australians (personal observations of the author).

Tindale (1981) suggested there was evidence from the excavation of the Ngautngaut rock shelter (Devon Downs area) in 1929 that hunter-gatherers placed fish resources under pressure because the otoliths and vertebrae of Murray codfish at the beginning of the Pirrian period near 5000 BP represented very large fish, but by early Mudukian period these remains were all of far smaller fish of that species. Balme (1983) collected golden perch and Murray cod otoliths from middens in the lower Darling River, near Tandou and suggested that the differing length-frequency distributions of golden perch (as determined from the otoliths) could reflect exploitation of local fish stocks, the use of various fishing techniques or differing environmental conditions at the time of capture.

Development of the commercial fishery

During the mid to late 1800s a large, commercial fishery developed and was based mainly on the Murray and Murrumbidgee rivers (Macleay *et al*. 1880; Dannevig 1903; Stead 1903). Large-scale operators used paddlesteamers as fishing boats (**Figure 4**), and caught cod using drum nets, gill nets and cross-lines. The drum net was introduced into the fishery about 1880 (Dannevig 1903; Stead 1903) and remained the most common method of netting Murray cod and other native species in inland rivers and creeks, until the closure of the NSW fishery in 2001.

By 1883, the Murray River fishery formed a considerable part of the fish supply to Melbourne, other Victorian cities and towns, and South Australia (Rowland 1989). In that year, more than 147 tons were sent to Melbourne from just one port, Moama (Cox 1884). Although few data were available, it appears the fishery was based on Murray cod. In 1862, a company of six men and a number of Aborigines captured 2 – 3 tons of fish per week from the Murray River south of Deniliquin, which 'abounded with fish, particularly Murray River cod' and sent them to Bendigo and Melbourne (Jervis 1952). The Fisheries Inquiry Commission of 1879 – 80 (Macleay *et al*. 1880) was told by Mr F.A. Thompson of Wagga, in relation to the fish in the Murrumbidgee River:

> the cod is the most prominent and remarkable …It is brought to market more plentifully than the others …a ton of fish is brought in here every week …I saw 150 large cod alive in a cart … They were sold in two hours or less.

The dominance of Murray cod in commercial catches is shown in **Figure 4**, the catch on the paddlesteamer Mayflower near Renmark in 1911. Dakin and Kesteven (1938) referred to 'the overwhelming importance of cod, the quantity of golden perch and silver perch taken is small compared with the quantity of cod.'

Photo courtesy of Ray Gregg

Figure 4. Catches of Murray cod aboard the paddlesteamer 'Mayflower' near Renmark in 1911 (top), and by recreational fishermen the late Isaac (Ike) Rowland and Gus Yates from the Barwon River near Walgett in 1962 (bottom)

Reduced abundance

Dakin and Kesteven (1938) presented available data on the catch of native fish between 1883 and 1938, and allowing for the limitations as discussed by the authors, the data indicate that although large fluctuations of fish populations occurred in the Murray-Darling River system, there was a gradual decline in the overall catch from a peak in 1918. By the mid 1930s, the commercial fishery had declined to an unprofitable level for the large-scale operators (Whitley 1937; Pollard & Scott, 1966).

Rowland (1985, 1989) presented data from the commercial fishery in inland NSW between 1940/41 and 1980/81 (see **Figure 5**) and later Reid *et al*. (1997) up-dated and analysed data from the fishery. The annual catch of Murray cod increased between 1940/41 and 1955/56 but then the total catch and catch per licensed fisherman declined dramatically (**Figure 5**). Murray cod was the major species in the fishery until 1951/52, and between 1940 and 1951 cod comprised 42 – 65% of the total annual catch from inland NSW. Although there was no change in fishing techniques, golden perch replaced Murray cod as the major species after 1951/52 (**Figure 5**). These data suggest that there was a dramatic decline in the abundance of Murray cod between 1955 and 1964. There was a concurrent decline in the commercial catch of Murray cod in South Australia (Reynolds 1976).

The catch remained low from 1980/81 to 1996/97 (Reid *et al*. 1997) and the NSW fishery for finfish closed in 2001. Although the low catch from the mid 1960s to the 1990s suggest that stocks remained stable, the data are not a good indication of the Murray cod stocks because of the very limited geographic extent of the fishery (only 5% of the linear distance of inland waters) and the significant decline in the number of commercial fishers from about 290 in 1972/73 to 40 in 1995/96 (Reid *et al*. 1997). There is no doubt, however, that the data demonstrate a significant decline in the abundance of Murray cod in the southern tributaries of the Murray-Darling River system. Unfortunately there is no data on the status of cod stocks in the northern part of the system where there was no commercial fishery.

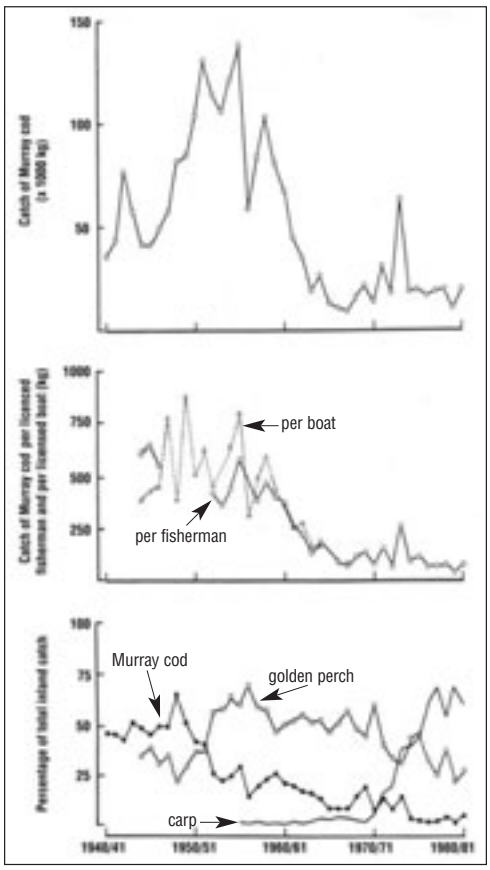

Figure 5. Catch data from the inland commercial fishery in NSW between 1940/41 and 1980/81. Top – total annual catch of Murray cod; middle – catch of Murray cod per licensed fisherman (○) and per licensed boat (△); and bottom – percentage composition of Murray cod (■), golden perch (□) and carp (—)

Reduced distribution

There was a reduction in the distribution of Murray cod in the 1900s, particularly in the upper reaches of the main rivers and smaller tributaries such as the Fish, Peel and Cudgegong rivers. Murray cod disappeared from the upper reaches of rivers such as the MacIntyre, Severn and Mole on the Northern Tablelands of NSW (Ray Mepham, members of the Tenterfield and Emmaville Angling Clubs, personal communication). Only relatively small populations are now found in waters impounded by the major dams such as Hume, Burrinjuck, Burrendong, Copeton, Pindari and Glen Lyon. In Victoria, Murray cod once abounded in the Loddon, Campaspe and Goulburn rivers and their tributaries (Wilson 1857), but by the late 1940s the populations of Murray cod and other

native fishes had declined in these rivers (Langtry, in Cadwallader 1977). There are now very few localities in Victoria where Murray cod can be considered common (Cadwallader & Backhouse 1983; John Koehn, personal communication).

Recreational fishing

Large numbers of Murray cod were easily caught and used as fresh food by early settlers (Bennett 1834; Macleay *et al*. 1880). Recreational fishing developed naturally as the inland towns and rural industries expanded. Graziers, shearers, farm hands, railway workers and townsfolk all have their stories of fishing for Murray cod and other native fish [Mr Hill, Jack Rosnow, Tom Hoare, Bill Mulholland, Howie Davison, Terry Maloney (1978 – 1980), Jim Mason (1996), personal communication]. People living on the land were keen fishers and had a particularly close bond with the fish and the inland rivers (Sinclair 2000). Even up to the 1960s, people in inland regions continued to catch and use fresh fish as an important part of their diet (Ike Rowland, Mr Hill, Jack Rosnow, Ray Mepham, Tom Hoare, personal communication). By the 1950s the popularity of inland fishing had increased tremendously and with the aid of motor vehicles, a relatively large recreational fishery had developed (Anon.1956). Large catches of Murray cod could be made by good recreational fishers using hand-lines and bait (**Figure 4**). There were few regulations on the recreational fishery in NSW until 1992 (there was a limit on the number of set lines, but no closed season, bag limit or size limit), and large catches, often using illegal techniques such as cross-lines, drum nets and wire traps were common in most waters (Jack Rosnow, Howie Davison, Barry Myers and other NSW Fisheries Officers, personal communication).

In the 1940s and 1950s, aeroplane spinners trolled behind row boats were also used to catch Murray cod (Pollard 1991; Tom Hoare, personal communication) and in the 1960s, a small number of pioneering fishers including Vic McCristal, Gordon Winter, Rod Harrison and Bryan Pratt started to use lures to catch Murray cod and other native fish. Lures are now commonly used by fishers and Murray cod is recognised as a fine sports fish, with many fishers practicing catch-and-release. Findings of the National Recreational and Indigenous Fishing Survey indicate that around 77% of Murray cod caught by fishers are released (Park *et al*. 2005).

Research and Management

Research and management of Murray cod were reviewed by Rowland (1985, 1989) and are briefly summarised below. Concerns about the stocks of Murray cod were expressed as early as the 1880 Fisheries Inquiry Commission (Macleay *et al*. 1880) and from 1883 until about 1895 there was some supervision of inland waters (Dakin & Kesteven 1938). There was an interstate conference on the Murray River Fisheries in Melbourne in 1902 and various resolutions were adopted: a closure of waters near Albury; a closed season for Murray fish from 1st September to 20th December; steps to establish a hatchery for indigenous fish; and no pike or other non-indigenous fish to be introduced without permission of state authorities (Dannevig 1903). Dannevig (1903) described the Murray cod fishery in detail, and suggested measures for restricting gear, protecting fry and young fish, and the imposition of a closed season. From 1905 to 1910 there were attempts to improve the cod fishery, including the first experiments into the artificial propagation of cod by Dannevig in 1905 (Farnell 1906; Dakin & Kesteven 1938). In 1936, a conference on the Murray River fisheries, attended by representatives from NSW, Victoria and South Australia, adopted a closed season of September, October and November for the taking of Murray cod; set minimum legal lengths; suggested that hatcheries be established; asked the Murray River Commission to construct a fishway at Lock 15 Euston; and suggested that the breeding habits and migration of freshwater indigenous fishes be studied by each State (Isherwood 1939).

A number of major studies have contributed to our knowledge of the life history of Murray cod. Dannevig (1903) presented information obtained from fishermen on the breeding season, spawning sites and size at maturity, and Stead (1903) described the breeding season, predators, and two types of cod. Dakin and Kesteven (1938) presented notes on natural history, behaviour in captivity and the spawning season. They discussed the cod fishery including evidence for and possible causes of declining stocks, reported artificial breeding trials using wild fish, described the eggs, embryonic development, larvae and fry, and emphasised the need for future research into the biology and breeding of cod. Colonel J.O. Langtry undertook a major

ecological survey of the Murray River and some of its tributaries in 1949/50; his manuscript was later published by Cadwallader (1977). Langtry described the differences between Murray cod and trout cod, provided data on fish distribution and abundance, and described the diet, breeding biology and growth of Murray cod. During the 1960s, John Lake studied the reproductive biology of native fishes at the Inland Fisheries Research Station (now the Narrandera Fisheries Centre), and his research demonstrated that critical temperatures and rising water levels in earthen ponds (and it was presumed in the wild) triggered spawning in some species including Murray cod (Lake 1967a, b).

Several major research projects into Murray cod commenced in the late 1970s. Scientists studied the artificial breeding, reproductive biology, and age and growth of Murray cod in Victorian waters (Cadwallader & Gooley 1985; Anderson *et al*. 1992; Gooley 1992; Gooley *et al*. 1995), and Rowland (1985) developed artificial breeding techniques and studied aspects of the biology of Murray cod to provide a basis for hatchery production and management of the species in NSW waters. Kearney and Kildea (2001) reviewed the status of Murray cod in the Murray-Darling Basin, and considered that while the persistence of the species is not of immediate concern, the integrity of wild populations (genetic biodiversity) and the ecological systems which support them (ecological diversity) are seriously threatened. They suggested a number of policy and management initiatives. Current management policies for Murray cod in each of the states and the Australian Capital Territory are presented by Lintermans (2005).

Biology of Murray Cod – age and growth, and reproductive biology

Age and growth

Initial studies of the age and growth of Murray cod were done by Llewellyn (1966), Lake (1967c), Jones (1974) and Langtry (in Cadwallader 1977) using scales or whole otoliths, but sample sizes were small, few age classes were included, and techniques were not described or validated. Rowland (1985, 1998b) used whole otoliths and opercular bones to age 330 cod (total length, TL, range 167 – 1270 mm; weight 0.07 – 40.0 kg) from the Murray, Edward, Wakool, Murrumbidgee, Darling and Gwydir rivers and two impoundments Lake Mulwala and Lake Burrinjuck in NSW. Anderson *et al*. (1992) used thin transverse sections of otoliths to age 290 (TL to 1400 mm; weight to 47.3 kg) from the lower Murray-Darling Basin, and Gooley (1992) used burnt, polished half sections of otoliths to age 303 Murray cod from Lake Charlegrark, western Victoria. In these studies techniques were validated using known-age fish, analysis of seasonal changes on the margins of the bony structures, and comparison of observed and back-calculated mean lengths-at-age.

Annual growth checks are formed on the otoliths and opercular bones (see **Figure 6**) of Murray cod in spring enabling the accurate ageing of individual fish. Murray cod is a long-lived fish, with the oldest cod aged in each study being 48 years (Anderson *et al*. 1992), 34 years (Rowland 1985, 1998b) and 22 years (Gooley 1992). Growth in length is described by a von Bertalanffy growth curve (**Figure 7**) with maximum lengths of 1369 mm (Rowland 1985, 1998b), 1202 mm (Anderson *et al*. 1992) and 695 mm (Gooley 1992). Whitley (1955) stated that cod grow to 1800 mm, and the 113.6 kg cod caught in the Barwon River in 1902 would have been approximately 1750 mm according to the length-weight relationship of Rowland (1985, 1998b). It is apparent that Murray cod can exceed the observed and theoretical maximum lengths reported in these studies.

Figure 6. Opercular bone of a Murray cod (total length 815 mm, weight 13.3 kg) sampled from Lake Mulwala in June – age 6 years, 8 months (from Rowland 1985, 1998b)

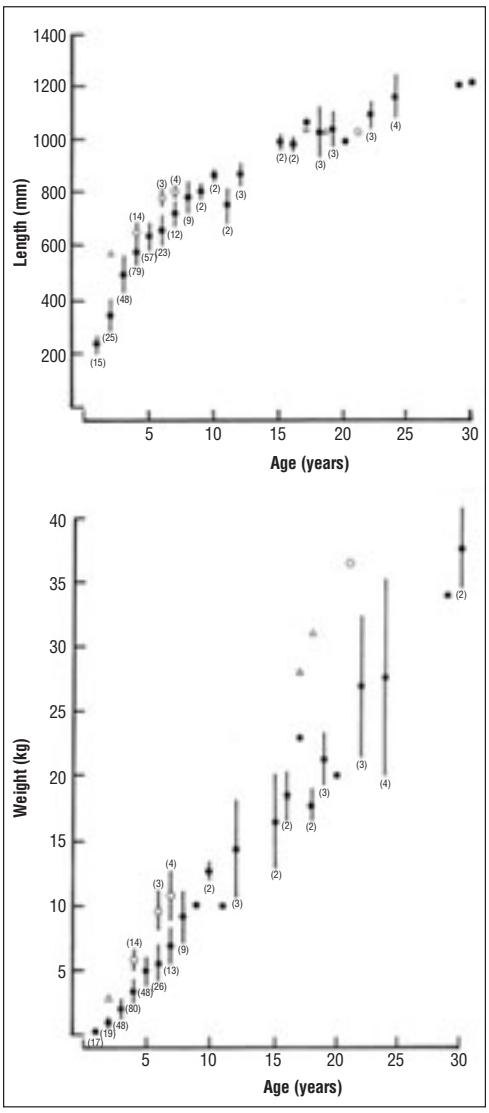

Figure 7. Growth of Murray cod in length (top) and weight (bottom) (from Rowland 1985, 1998b; data are means ± SD; ● – cod ex rivers, ○ – cod ex Lake Mulwala, △ – cod ex Lake Burrinjuck)

The growth rate of Murray cod is relatively slow (K=0.060), which is consistent with long-lived fishes. Rowland (1985, 1998b) and Gooley (1992) found no significant differences in the growth of males and females, whereas Anderson *et al*. (1992) found a difference using fish from both historical and recent samples and on average larger fish than the two other studies.

Length-weight relationships in the studies were similar [$W = 3.240 \times 10^{-9} \times L^{3.26}$ (Rowland 1985, 1998b); $W = 3.15 \times 10^{-5} \times L^{3.26}$ (Gooley 1992)].

The high value of the constant b (3.26) indicates that Murray cod become more and more rotund as length increases; from about 10 years of age, cod grow predominantly by increases in weight. From ages 10 to 30 years, there are large variations between the weights of same-age fish and there is no asymptote apparent in the age-weight relationship of Murray cod up to 30 years of age (see **Figure 7**). Anderson *et al*. (1992) also reported large variations in weight of same-age Murray cod.

Growth rates of Murray cod vary across the Murray-Darling River system. Cod from Lake Mulwala and Lake Burrinjuck are significantly larger than same-age cod from rivers (Rowland 1985, 1998b), and these in turn grow faster than Murray cod in the southern, colder environments of Lake Charlegrark (Gooley 1992). In general, Murray cod older than 5 years grow at a rate of 1 to 1.5 kg per year in rivers and 2 to 2.5 kg per year in impoundments such as Lake Mulwala, Lake Burrinjuck and Copeton Dam. Using the general growth rate of cod in rivers the largest cod caught, 113.6 kg, may have been between 76 and 114 years old (Rowland 1988a).

Reproductive biology

Studies of Murray cod held in earthen ponds have provided some information on the reproductive biology of the species. Cod spawn large (3 mm), adhesive eggs onto firm substrates such as hollow logs, pipes and clay banks in spring and early summer (Lake 1967a; Rowland 1983a; Cadwallader & Gooley 1985). Lake (1967a) found that a slight 'runoff' of water into a pond induced cod to spawn, but the later studies by Rowland (1983a) and Cadwallader and Gooley (1985) demonstrated that spawning was not dependent on a rise in water level in ponds. Spawning in ponds usually occurs when water temperatures are from 16° to 20°C (Rowland 1983a; Cadwallader & Gooley 1985). Embryology and larval development were described by Dakin and Kesteven (1938) and Lake (1967a), and Rowland (1983a) observed paternal protection of eggs in earthen ponds.

Murray cod has a distinct seasonal cycle; monthly gonadosomatic indices (GSI) and mean oocyte diameters are low between December and March, increase rapidly from June, presumably due to vitellogenesis, and are highest in October.

Oocytes undergo group-synchronous development, but only one batch of yolky oocytes is spawned in spring. Rowland (1988b) found that the handling of sexually mature Murray cod within three months of the breeding season induced atresia and resorption in most females. Rowland (1998a) suggested that the relatively high catch rate of cod, including pairs, in September and difficulty in catching spent males in late October and November were a result of increased activity of broodfish associated with spawning site selection and mating, and paternal protection of the eggs (and possibly larvae) at the spawning sites. Koehn (1996) and Koehn and Nicol (1998) reported upstream movement of adult Murray cod in the Ovens and Murray rivers during late winter-spring-early summer period and suggested this was associated with spawning. There is also downstream drift of Murray cod larvae. In the Murray River, cod larvae (length ~ 11 mm) drift for up to 4 days commencing in late October, with peak numbers in a 4 week period in November (Gilligan & Schiller 2003). These authors expressed concern that cod larvae may be lost from rivers as they enter irrigation channels over the course of the irrigation season. The diets of Murray cod larvae are reported to be crustacean zooplankton in fertilised earthen ponds (Rowland 1992; Ingram 2001) and benthic invertebrates in the river channel (King 2002).

Spawning is temperature-dependant and so the actual season varies latitudinally. Rowland (1983a) found that Murray cod spawned in ponds at Narrandera when water temperatures rose to or above 20°C in late September and October. Spawning commenced in the Wakool River in southern NSW after the water temperature rose above 20°C in late October, whereas in the northern Gwydir River spent females were caught in early October when temperatures were between 20°C and 22°C (Rowland 1985, 1998a). Cod held in ponds in northern NSW breed in early spring when temperatures reach 20°C, usually late September and early October (Ray Mepham, Phil Forster, personal communication). During this period, the actual spawning of broodfish in ponds is often induced by afternoon or evening storms (Ray Mepham, personal communication). At Lake Charlegrark and Snobs Creek, near the southern limit of Murray cod's natural range, most spawnings occur during November at temperatures between 16.5°C and 23.5°C (Cadwallader & Gooley 1985; Gooley *et al.* 1995; Brett Ingram, personal communication). The breeding season of Murray cod in the lower Murray River around Boundary Bend is always finished by December (Maurie and Joy Forster, personal communication).

The preferred natural spawning sites of Murray cod in the wild have not been positively identified. Aborigines captured cod in the spawning season from 'deep erosion cavities' that were up to 10 to 15 feet under water at the base of limestone cliffs on the Murray River (Tindale 1951). Many fishermen in the commercial fishery of the late 1800s thought cod selected 'certain places along the steep banks for depositing its spawn', and the Chief Assistant Inspector of Fisheries stated that cod spawn among reeds, hollow logs, trees, and particularly sandy banks, backwaters, and billabongs, but not in muddy, stagnant billabongs (Dannevig 1903). Macleay *et al.* (1880) and Langtry (in Cadwallader, 1977) described depressions on clay and silt banks, sheltered from the main flow in rivers as cod spawning sites. After finding eggs in cement pipes in ponds, Lake (1967a) assumed that hollow logs and similar structures were used in the wild, and subsequent literature states that hollow logs are used by Murray cod. Rowland (1983a) and Cadwallader and Gooley (1985) found cod eggs deposited on firm substrates such as concrete raceways and banks of earthen ponds demonstrating that spawning is not confined to hollow structures, and the sites on pond banks in those two studies were similar to those described by Macleay *et al.* (1880) and Langtry.

Spawning of Murray cod both in ponds and in the wild is independent of changes in water level (Rowland 1983a, 1998a; Cadwallader & Gooley 1985). Rowland (1985, 1998a) found many consecutive year-classes in each of the Murray, Murrumbidgee, Edward, Wakool and Gwydir rivers and suggested that Murray cod must spawn annually in the wild irrespective of changes in water level. However, between 1977 – 1980 strong year-classes were established in the Murray, Edward and Murrumbidgee rivers only when the breeding season coincided with high river levels or floods, suggesting that floods in October or November provide optimum conditions for the survival and recruitment of larvae and juveniles in this part of the Murray-Darling River system.

Absolute fecundity of Murray cod in rivers ranges from 6,800 (TL 480mm, weight 2.1kg) to 86,600 (1050mm, 22.7kg). Relative fecundity ranges from 3.2 to 7.6 eggs/g, and limited data suggests it may decline with increasing size in fish over about 10 kg (Rowland 1985, 1998a).

There are differences in the age and size at sexually maturity between Murray cod populations. Rowland (1985, 1998a) found no females and a few males had matured by 3 years of age, but at 4 years of age, 77% of females (> 480mm, 2.1kg) and 72% of males (> 530mm, 2.3kg) were mature and at 5 years all females and most males were mature. All cod larger than 590mm and 3.9kg in rivers were mature, but the smallest sexually-mature cod sampled from the impoundment, Lake Mulwala, was 610mm and 5.0kg. These data suggest that first maturity in Murray cod in most NSW waters is determined by age, not size. However, in Lake Charlegrark, females mature at approximately 6 years of age and 2 kg, and males at 3 – 4 years of age and 700 g (Gooley *et al*. 1995) demonstrating some plasticity in this aspect of the species' biology.

The following observations and data suggest there may be decreasing reproductive performance with increasing size in Murray cod: (i) decreasing relative fecundity with increasing size, over about 10 kg; (ii) large females (> 30kg) generally produce poor quality eggs, with low fertilisation and hatch rates under hatchery conditions; (iii) degeneration and calcification of ovarian tissue is common in large females (> 40 kg) in the wild (Don McGilvray, Jack Rosnow, personal communication; personal observations of author).

Biological data applied to management

A knowledge of the cod's biology was used to impose restrictions on the early commercial fishery (Dannevig 1903; Dakin & Kesteven 1938; Isherwood 1939). A closed season of September, October and November, as well as some gear restrictions (number of nets, mesh sizes) were imposed on the commercial fishery in NSW before the 1960s (Max Withnell, Chief Fisheries Officer, personal communication). However, there were few restrictions on the rapidly growing recreational fishery between the 1950s and 1990s. The study by Rowland (1985) was undertaken at the direction of the former NSW Fisheries scientists Chief Biologist, Dr Bruce Malcolm, and Senior Freshwater Biologist, Mr Fred Reynolds, to provide base-line biological data for the formulation of fisheries management policies and regulations for Murray cod recreational fishery in NSW. In 1992, NSW Fisheries introduced the following restrictions to this fishery: (i) a 3-month closed season (September, October, November) to protect cod during the breeding season; (ii) a minimum size limit of 50 cm to ensure most fish retained by fishers were sexually mature and had the opportunity to breed before capture; (iii) a bag limit of 2 fish/day and a possession limit of 4 fish to reduce fishing mortality. In general, these fishing regulations have been very well received by fishers (Bill Mulholland, Les Rava, Phil Forster, Ray Mepham, Tom Hoare, Terry Maloney, Jim Bailey, Rob Loats, Richard Ping Kee, personal communication) and compliance has been high (Fisheries Officers, NSW Fisheries, personal communication).

Reasons for Decline (in chronological order)

There is no doubt that many factors have contributed to the decline of Murray cod, some with only localised effects, others with much broader effects. Siltation, desnagging, channelisation, cold-water pollution, barriers preventing migration, pollution and fish kills have all been rightly implicated (Merrick and Schmida 1984; Harris & Rowland 1996; Koehn 1996); however, the author suggests that the following are the major factors that caused the decline of Murray cod across its range since the mid 1800s.

Over-fishing

Between the late 1880s and 1930s

The large inland commercial fishery, which was based primarily on the Murray and Murrumbidgee rivers and their tributaries would have placed intense fishing pressure on cod populations between the mid 1800s and the late 1930s. Long-lived species with long generation periods, low natural mortality rates and slow growth are very susceptible to over-fishing (Reynolds *et al*. 2002). Previously unfished populations of long-lived fishes are extremely susceptible to exploitation, and with unchanging recruitment the absolute size of the total stock will decline markedly, or even catastrophically under moderate exploitation (Ricker 1963).

An extended age distribution in fishes such as Murray cod represents an evolutionary adaptation by which potentially high larval mortality in unfavourable breeding seasons is compensated for by repeated annual spawnings over the life span of the individuals (Giesel 1976; May 1976). It is therefore probable that the decline in abundance of Murray cod, at least until the 1930s, by which time the fishery was unprofitable for large-scale operators, was caused primarily by over-fishing.

Rowland (1989) suggested that a possible reduction in the exploitation of cod after the 1930s due to the depressed state of the fishery, the Depression and World War II, may have resulted in cod numbers and the catch per licensed fisherman/boat remaining stable or even increasing (see Figure 5) until the late 1950s when effects of redfin and reduced survival and recruitment of Murray cod larvae and juveniles caused by river regulation became apparent in rapidly declining stocks.

1970s and 1980s

Over-fishing by the commercial fishery could not have been the major cause of the decline of Murray cod in the central and northern tributaries of the Murray-Darling River system because the fishery was restricted to the southern tributaries (Dannevig 1903; Dakin & Kesteven 1938; Rowland 1989), with the exception of some ephemeral lakes in northern NSW where there are no or very few Murray cod (Barry Myers and Fisheries Officers, personal communication). In the 1970s, when stocks of Murray cod in the Murray, Murrumbidgee, Lachlan and their tributaries were very low, northern tributaries such as the Darling and Barwon rivers were regarded as the 'strong-hold' of Murray cod and other native fish (Dr Leighton Llewellyn, Fred Reynolds, Barry Myers, personal communication). Through the 1970s and 1980s, there were increasing numbers of recreational fishers in western NSW (Barry Myers and other Fisheries Officers, NSW Fisheries, personal communication), partly associated with growing popularity and use of 4WD vehicles and the desire of many Aussies to travel and experience the outback. The expanding recreational fishery, plus illegal fishing which was usually targeted at Murray cod, may have contributed to a decline of cod through fishing mortality in this part of the system during these decades.

Fish kills caused by toxic chemicals in the early 1900s

In the first half of the 1900s, Murray cod and other native fish including golden perch declined significantly or became extinct from some parts of the Murray-Darling River system where there was no commercial fishery, no apparent habitat degradation, and only limited recreational fishing because of the sparse human population and the relatively rugged, isolated country. These areas included the waters of the Northern Tablelands of NSW such as upper reaches of the Gwydir, MacIntyre, Mole and Severn rivers and their tributaries (Ray Mepham, Phil Forster, members of the Tenterfield and Emmaville Fishing Clubs, personal communication).

Although reasons for the demise of native fishes in these waters are not clear, it is thought to be linked to numerous, regular fish kills which followed the release of water from sheep dips (Ray Mepham, personal communication). The Northern Tablelands of NSW has always been prime sheep country, and graziers located sheep dips close to rivers and creeks for access to water, and convenient release of the solution after the dipping process. In the early 1900s, arsenic-based chemicals were used to treat parasites such as lice (O'Gorman 1938) and it is possible that the release of contaminated water from these dips caused the reported fish kills and disappearance of Murray cod and other native fish. The use of such chemicals and practices ceased before the 1950s (Gary Levot, David McIver, NSW Department of Primary Industries, personal communication), and these fisheries have returned to near historic levels (see later section).

Predation by, and competition with the introduced species redfin* (Perca fluviatilis) *in the mid 1950s

Redfin (or English perch) was abundant and sympatric with Murray cod in the Murray, Murrumbidgee and Lachlan rivers and their tributaries between the late 1940s and the 1960s (Lake 1967c; Langtry, in Cadwallader 1977; Roberts & Sainty 1996). Langtry (Cadwallader, 1977) found that the diet of redfin was identical to that of Murray cod and golden perch, and small fishes become a major part of the diet of larger redfin (Lake 1967c). Redfin larvae and juveniles feed on zooplankton, crustaceans and insect larvae, and because redfin spawns in early spring when temperatures are about 12°C,

usually the last week or so in August in southern NSW waters (Lake 1967c), juvenile redfin have the opportunity to prey on, and possibly compete for food with Murray cod larvae and juveniles, particularly if food resources are limited. The catch data on fishes from the Kerang Lakes in Victoria, between 1919 and 1949 (Cadwallader 1977) demonstrated that when redfin was abundant, native fish were scarce and *vice versa*. It is therefore possible that redfin contributed to the dramatic decline of Murray cod in the southern parts of the Murray-Darling River system between the mid 1950s and 1960s.

Reduced survival and recruitment of larvae and juveniles since the 1950s

The high survival of fish larvae is dependent of the availability of relatively high concentrations of suitable-sized food organisms at the commencement of exogenous feeding; sub-optimal feeding conditions generally result in high mortalities due to starvation or predation (May 1974; Pitcher & Hart 1982). The degree of mortality during a 'critical period' after the completion of yolk sac absorption is considered to be a major factor determining the strength of year-classes in natural populations (Hjort 1926; May 1974; Pitcher & Hart 1982; Cushing 1990; Myers 2002).

Rowland (1985, 1992, 1996; Ingram, 2001) described the diets of larval Murray cod and golden perch at first feed, and demonstrated that under aquaculture conditions (i.e. in aquaria and earthen ponds) high densities of the crustacean zooplankton copepods and cladocerans are necessary for high survival of larvae, and that a delay in zooplankton availability significantly reduces survival. Although Murray cod spawn annually, strong year-classes are only established when the breeding seasons coincide with high river levels or floods suggesting that floods in spring provide optimum conditions for the survival and recruitment of Murray cod larvae and juveniles in riverine environments (Rowland 1985, 1989, 1998a). Floodplains are recognised as playing an important role in the ecology of larval and juvenile native fish (Geddes & Puckridge, 1989; Richardson 1994) and those of the Murray-Darling River system are highly productive and produce a rich source of nutrients, plankton, aquatic insects and other aquatic organisms when inundated (Frith 1959; Shiel 1980; Maher & Carpenter 1984).

However, the construction of dams, high level weirs and levee banks on the major tributaries of the system has altered the natural flow and temperature regimes and dramatically reduced the frequency, extent and duration of floods (Lake 1971; Cadwallader 1978; Walker *et al*. 1978; Walker 1979). Consequently, optimum conditions for the survival and recruitment of Murray cod now rarely occur. It is suggested that river regulation played a significant role in the decline of Murray cod since the mid-1950s when the cumulative effects of the major impoundments and water storage schemes would have become apparent (Rowland 1985, 1989).

The Murray cod scenario supports the 'flood-pulse concept' of fish recruitment, but in recent years some studies have questioned the link between floods and fish recruitment in the Murray-Darling River system (e.g. Humphries *et al*. 1999; King *et al*. 2003; Mallen-Cooper & Stuart 2003). These studies reported non-flood recruitment of species such as golden perch and silver perch, and poor recruitment under flood conditions. Many factors are likely to impact on fish recruitment in this complex and at times harsh system including the degree of environmental degradation and modification of the river channels and floodplains, differing degrees of regulation and water allocation between rivers, differences in morphology and hydrology between rivers, the presence and influence of introduced fishes, the presence/absence and density of adult fish, species-specific requirements for spawning, egg incubation and hatching, and the timing, extent and duration of floodplain inundation. The actual mechanisms and associations between river flow, floodplain inundation, adult fish stocks, larval food production and recruitment, and loss of larvae through water extraction are poorly understood for Murray cod and other species, and more research is required before appropriate environmental management policies can be developed for the benefit of native fishes in the Murray-Darling River System.

Recovery of Murray Cod in NSW Waters

Increased distribution

Major stocking programs since the late 1970s have increased the distribution of Murray cod in some areas, and played an often unrecognised role in the conservation of this species (Rowland 1995). Ray Mepham and his family of Elsmore, near Inverell in northern NSW, commenced restocking the upper MacIntyre River with Murray cod in the early 1970s. Ray was the first person after the late John Lake, to breed Murray cod in captivity. Ray collected mature cod from lower parts of the MacIntyre River, held them in large dams on his property, and then in January and February each year collected fingerlings that had been bred naturally in the dams and used them to restock the local rivers and creeks. Following the lead of the Mepham family, members of the fishing clubs in Tenterfield, Glen Innes, Emmaville and Ashford areas commenced stocking hatchery-bred Murray cod into the upper reaches of rivers on the NSW Northern Tablelands in 1979. In addition, a small group of concerned fishers, including Phil Forster and Merv Riley, planned and built the Bingara Angler's Club Hatchery at Bingara, northern NSW, in the early 1980s with significant support from the local council and community. Their aim was to produce Murray cod, golden perch and silver perch, which had declined dramatically in the Gwydir River following the construction of Copeton Dam. The regular stocking of these waters, using fingerlings from local hatcheries has contributed significantly to the conservation of Murray cod by returning the species to a part of its original distribution where it had declined significantly. These northern rivers now support one of the best Murray cod fisheries in Australia.

Increased abundance

Anecdotal information, including numerous reports from commercial and recreational fishers, articles in fishing magazines and newspapers, plus unpublished fisheries data suggest there has been an increase in the abundance of Murray cod in some NSW waters. Although very few Murray cod were sampled from the Murray Region in the NSW Fisheries' Rivers Survey (Harris & Gehrke, 1997) or the recent pilot Sustainable Rivers Audit (MDBC 2004), some commercial and recreational fishers were regularly reporting increasing numbers of under-size/immature cod (20 – 50 cm) being caught in drum and gill nets, and on set lines in southern NSW rivers such as the Edward, Wakool, Niemur and Murrumbidgee in the early 1990s (Howie Davison, Bill Mulholland, Les Rava, Terry Maloney, personal communication). This apparent resurgence of Murray cod continued through the 1990s, and current recreational catches of Murray cod in the Murray (below Yarrawonga Weir), Murrumbidgee (around and below Wagga Wagga), Edward, Wakool, Niemur and Macquarie rivers in southern and central NSW are described by most fishers as the best in many decades (Howie Davison, Rob Loats, Terry Maloney, Les Rava, Bill Mulholland, Bruce Malcolm, Noel Penfold, personal communication). Numbers of Murray cod have also increased in the lower reaches of the Gwydir River from Copeton Dam down to Moree (Phil Forster, Ray Mepham, Richard Ping Kee, personal communication). There is now excellent fishing for Murray cod in parts of the Barwon and MacIntyre rivers and Glen Lyon Dam in the border area of NSW and Queensland (Rod Cheetham, Les Kowitz, personal communication). Murray cod are now dominating fishing competitions such as the Tocumwal Classic 2001 and regular outings of angling clubs in the Riverina, whereas through the 1980s the dominant species was always carp (Terry Maloney, Bruce Malcolm, personal communication).

Many articles in fishing magazines and newspapers have reported large catches of Murray cod over the last 5 – 10 years. The following are some examples.

> Angler caution on cod catches. The huge number of Murray cod being caught down around Sunraysia has drawn a caution from the North West Anglers Association … More clear water is on its way and the fishing bonanza is set to continue… (Sunraysia Daily 27 January, 1997).
>
> … the 2002 season will be remembered locally as the year of the "mega" cod, with captures of fish in excess of 20 kg almost becoming a frequent event. …This section of the river [Murray River near Robinvale] has relatively recently undergone amazing transformation. Over the past few years the shallow fringes along the banks, once muddy and barren, have seen an explosion of weed growth due mainly to a dramatic increase in

> water clarity and the notable absence of the once prolific European carp. …I consider myself privileged to live on the doorstep of this special fishery … The 2002 season along this stretch of the river was the best I'd experienced with more big fish than I can remember being caught (Rod MacKenzie, Mighty Murray Mega Cod Season 2002, Freshwater Fishing Australia, Issue 59, Winter 2002).
>
> The Macquarie River has a well-established population of Murray cod that are thriving … This top-class fishery … the thriving population of Murray cod right on its [Dubbo] doorstep … Although the population seems to be booming, this is no reason to stop protecting it … anglers targeting large cod … being plagued by captures of juvenile cod from 20cm to 45cm … (Nigel Webster, Cod on Dubbo doorstep, New South Wales Fishing Monthly, June 2004).

The stocks of inland fish have not been deliberately monitored by NSW Fisheries or any other authority since the closure of the commercial fishery in 2001. Although the data from that fishery provided an estimation of native fish stocks, its value over the last few decades has been limited because of the very restricted geographic distribution of the fishery and the significant decrease in the number of fishers; the data may not be a reasonable indication of Murray cod stocks through the 1980s and 1990s. However, over the period 1994 – 2004, there has been consistent sampling (technique and effort) of native fishes at different locations in the Murray-Darling River system by NSW Fisheries staff, and analysis of this 10-year data set indicates a consistent and positive trend in Murray cod populations across NSW (Dean Gilligan, unpublished data, 2004).

Factors contributing to the recovery

Although there is evidence of increasing distribution and abundance of Murray cod in NSW waters, the extent of the recovery is unclear because of a lack of fisheries data based on regular, long-term monitoring using effective sampling techniques and strategies. There is no doubt that numbers remain very low, and that the species is in significant trouble in Victoria waters. Besides the lack of data, the great complexities of the Murray-Darling River system and the biology of its fishes make key factors associated with any recovery very difficult to identify. The author suggests that the following factors may have contributed to the increased abundance of Murray cod in some NSW waters.

Good natural recruitment

A number of factors suggest that the recovery is at least partially based on years of good natural recruitment: (i) the broad geographic extent of the recovery (from the Murray River in the south, to the rivers on the Queensland border); (ii) the reported large number of cod of varying sizes up to 60 cm in many rivers; (iii) the limited number of hatchery-reared Murray cod stocked into rivers in NSW (see following); and (iv) the presence of good numbers of cod in some areas that have not been stocked or only stocked with low numbers, e.g. the Darling River. Although the 1990s has been a relatively dry decade, conditions for good recruitment of Murray cod (high river levels in spring) have occurred in some years in most rivers (Department of Infrastructure, Planning and Natural Resources, river height data).

Dakin and Kesteven (1938) noted that there was a cyclic pattern in the abundance of Murray cod, with catches peaking each 17 years in 1883, 1900, 1918 and 1934, although they could not confirm if such cycles existed in nature. Some elderly fishers have long recognised cycles in the range of 15 – 20 years in the abundance of cod (Mr Hill, Jack Rosnow, 1978, personal communication). It is interesting to note that the distinct peak in catches of cod in the early 1950s (*Figure 5*) is about 20 years after the peak in 1934 as reported by Dakin and Kesteven (1938). This begs the question 'Is the current recovery of Murray cod part of one of nature's cycles?'

Protection of stocks through fishing regulations in NSW

Closed seasons, bag limits and size limits are common fishing regulations, often used in combination to achieve objectives (King 1998). Closed seasons aim to protect breeding stocks and if imposed in a well-defined season can allow adults to breed without interference (King 1998; Cowx 2002). Murray cod has a well-defined spawning season of September – October in northern NSW and October – November in southern areas. The increased activities associated with spawning site selection and protection, mating and spawning are well recognised and increase the susceptibility of cod to capture.

In the old commercial fishery, a bulk of fish were caught in the spring months (Dannevig 1903). Stead (1903) reported that August, September and October are the best months for catching cod because '*… then the greatest number is caught and they are nearly all large females and full of roe. Even those who use drums all year round agree that the months mentioned are the best*'. Dakin and Kesteven (1938) stated that '*the most easily accomplished method of conservation is to see that the closure during the breeding season is satisfactorily imposed*'. More recent research and observations support these statements. Rowland (1985) reported a higher catch rate of cod, including pairs of cod in September compared to August, October, November and December in the Edward and Wakool rivers. Relatively large numbers of adult Murray cod were captured illegally using drum nets, wire traps and cross-lines at the commencement of each closed season for the commercial fishery (i.e. in August-September) (Barry Myers and other Fisheries Officers, Jack Rosnow, Howie Davison, Maurie and Joy Forster, personal communication; personal observations of the author). It is likely that this illegal activity and the recreational fishery which often targeted cod during the breeding season because of increased catchability, contributed to high levels of fishing mortality as well as disruption of breeding activities prior to 1992.

Minimum size limits are applied to allow small fish to grow larger so they can reproduce at least once before capture (King 1998). Most, but not all Murray cod are sexually mature at 50 cm, and so this regulation would partly achieve its objective, as well as reducing fishing mortality. Fishing regulations are also a constant reminder to fishers and the general community of the need for moderation and conservation in fishing.

All states and the ACT have fishing regulations for Murray cod (Lintermans 2005). In NSW, the closed season, size limit and bag limit in the recreational fishery were introduced 12 years ago in 1992, and the commercial native finfish fishery was closed in 2001. The recovery of Murray cod stocks in NSW waters may be a response to the protection of adult cod during the breeding season, to an increased number of fish reaching sexual maturity, and to an overall reduction in fishing mortality. The author considers that these fisheries regulations have played a significant role in the recovery of Murray cod in NSW waters over the last 10 years.

Stocking of hatchery-reared fingerlings

The stocking of hatchery-reared fry or fingerlings is an important management tool in freshwater fisheries, and has significantly enhanced populations of native fish in parts of the Murray-Darling River System where natural reproduction does not occur or is only partially successful, but where the habitat remains suitable for juvenile and adult fish (Rowland 1995). There is no doubt that stocking has contributed to an increase in the distribution of Murray cod, both within the Murray-Darling River System and outside its natural range through translocation.

Murray cod produced by NSW Fisheries at the Narrandera Fisheries Centre are stocked only into impoundments for stock enhancement, whereas cod produced at the Victorian Government hatchery at Snobs Creek are stocked into rivers and creeks as well as impoundments. Some of the cod produced at commercial hatcheries are sold to angling clubs and acclimatisation societies for stocking public waters. A joint NSW Government and community stock enhancement program involving commercial hatcheries, the 'Dollar for Dollar Native Fish Stocking Program', commenced in 1999 and a total of 919,000 Murray cod have been stocked in the 5 years of the program (Craig Watson, personal communication).

The number of cod released annually has increased exponentially since the 1970s, and a total of 6.9 million fingerlings have been stocked, mainly in Victoria and NSW (Ingram *et al*. 2004). There have been relatively few stockings in other states and in the ACT. Despite the relatively large number of Murray cod stocked in Victoria since the late 1980s (Ingram *et al*. 2004), the species is still uncommon in most waters, suggesting very limited success of the stocking program in that state. Dr Brett Ingram (Department of Primary Industries, Victoria) is currently reviewing the stocking of Murray cod in eastern Australia; 75% of cod have been released into impoundment (dams, reservoirs, lakes), and only 22% into rivers and creeks and 3% into weirs. In NSW, a vast majority of cod have been stocked into impoundments, and less than 1% into waters west of Longitude 146°. These records suggest it is unlikely the stocking of hatchery-reared Murray cod has been responsible for the increased abundance in NSW rivers. It is possible, however, that the stockings may be masking the status of riverine populations, especially those in eastern parts of the system.

Decreased numbers of redfin and carp

Although few studies have been able to establish cause and effect, redfin and carp are thought to have harmful effects on aquatic habitats and native fish species (Cadwallader & Backhouse 1983; Rowland 1989; Harris & Gehrke 1997; Koehn *et al*. 2000). Redfin were prolific in the 1940s – 1960s in southern tributaries of the Murray-Darling River System (Langtry, in Cadwallader 1977; Lake 1967c; Roberts & Sainty 1996), and the explosion of the carp population commenced in the mid 1970s with carp dominating the fish fauna in many parts of the system (Harris & Gehrke 1997; Koehn *et al*. 2000). These decades coincide with the dramatic decline of Murray cod and the period when stocks remained at low levels. Redfin have been uncommon in the lower reaches of the Murray and Murrumbidgee rivers and most western and northern waters in NSW (except for Copeton Dam and Beardy Waters near Glen Innes and Inverell) for decades (NSW Fisheries freshwater data base; Roberts & Sainty 1996), although they are still common in the upper reaches of some rivers. The decline of redfin since the peak in the 1960s would have reduced predation and competition with Murray cod and other native fish in these waters. It is clear that the decline of cod occurred well before the carp explosion in the mid 1970s (Rowland 1989). There has also been an apparent decline in carp numbers in some parts of the Murray-Darling River System, but not others in recent years (Dean Gilligan, unpublished data) and anglers in the Murray, Murrumbidgee and Lachlan rivers report catching no or relatively few carp over the last 2 or 3 years (Les Rava, Terry Maloney, Rob Loats, Lance Parker, personal communication); see also the previous comments by Rod MacKenzie in Freshwater Fishing Australia. The reduced numbers of these introduced fishes may have contributed to the recovery of Murray cod. Both redfin and carp are known to be common food items of Murray cod (Cadwallader & Backhouse 1983; Rowland 1988a; Jack Rosnow, Howie Davison, Maurie and Joy Forster, personal communication), and although the relationship between predators and prey are complex, the increasing numbers of Murray cod over the last 10 years may in itself be contributing to the apparent decline of carp in some NSW waters.

Improved environmental conditions

Over the last decade, numerous initiatives have been undertaken by the Murray-Darling Basin Commission, various Commonwealth and State Government authorities, local councils, community groups, farmers and private interest stakeholders to address concerns about the poor health of inland aquatic environments. Improvements have been, or are being made in many areas such as water sharing allocations and environmental flows, desnagging, management of riparian vegetation, salinity, irrigation practices, pesticide use, farming practices and fish passage at low and medium level weirs. Improved environmental conditions in some parts of the Murray-Darling River System may be facilitating the recovery of Murray cod.

Aquaculture

Hatchery production

Techniques for the large-scale hatchery production of Murray cod, as well as golden perch and silver perch were developed by the early 1980s (Rowland 1983a, b, c; Rowland *et al*. 1983; Cadwallader & Gooley 1985) and in 1982/83 commercial hatcheries in NSW, Queensland and Victoria started to produce fingerlings (Rowland & Tully 2004). Broodfish are collected from the wild and held in earthen ponds. Murray cod spawn readily in ponds over many consecutive years (Rowland 1983a; Cadwallader & Gooley 1985; Ray Mepham, Bruce Malcolm, Phil Forster, Stephen Thurstan, Noel Penfold, personal communication) and fertilised eggs are collected from drums placed in the ponds prior to the breeding season. Eggs can be stripped and fertilised after the induction of final oocyte maturation and ovulation using the hormone human chorionic gonadotrophin, HCG (Rowland 1988b), but this technique is labour-intensive and the quality of eggs is variable, and so is rarely used at Government or commercial hatcheries. Eggs are incubated in the hatchery and larvae are reared in earthen ponds that have been fertilised to promote blooms of phytoplankton and zooplankton (Rowland 1983 a, b, 1992). Pond management techniques have improved significantly over the last 10 years (Ingram 2001; Stephen Thurstan, personal communication) and survival of Murray cod to sizes of 30 – 50 mm average 75% and can be as

high as 90% (Ingram 2001). Today hatchery production of fingerlings is routine and efficient (Ingram *et al.* 2004a).

Fingerlings are stocked into impoundments, rivers and creeks, and farm dams in south-eastern Australia for stock enhancement, conservation and recreational fishing. Between 200,000 and 800,000 fingerlings were produced annually during the 1990s, and in 2000/01 season a record 1.79 million was produced (Ingram & Lawson 2004). Currently about 50% of all fingerlings produced are sold to commercial grow-out farms (Ingram & Lawson 2004).

Grow-out to market-size

Production of Murray cod for human consumption is a relatively new industry, with fish first entering the market in the early 1990s (Gooley & Rowland 1993). Since then the industry has grown to 103 tonnes valued at $2 million in 2001/02 (Ingram & Lawson 2004). Many cod are produced in tank-based, re-circulating aquaculture systems (RAS) with production rates of 80 – 280 kg/m^3 depending on the aeration system used; oxygen is necessary to achieve rates above 100 kg/m^3 (Ingram & Lawson 2004). Fish are grown to 600 g – 3 kg, purged to eliminate off-flavours and then sold through fish markets, wholesalers, distributors, restaurants and direct to consumers (Ingram & Lawson 2004; Larkin *et al.* 2004). Murray cod are susceptible to a number of diseases and so health management is a very important component in the intensive culture of the species (Rowland & Ingram 1991; Ingram *et al.* 2004b). Some farms use a combination of RAS during colder months, and then stock fish into ponds in late spring and summer where they grow rapidly (Bruce Malcolm, personal communication). Fish are weaned as post-larvae and reared on high protein (50% protein) diets which may account for 20 – 30% of production costs (De Silva *et al.* 2004). Preliminary trials suggest Murray cod also has potential for cage culture (Ingram 2000; Ingram *et al.* 2004a).

The intensive culture of Murray cod is a difficult industry, and although there has been some research to develop production and husbandry techniques and species-specific diets, further R&D is necessary to enable significant expansion of the industry (Ingram 2004; Ingram *et al.* 2004a).

There is continuing interest in farming Murray cod for domestic and export markets, particularly in Asia because cod look like marine groupers which are highly sought-after, premium fish (Ingram *et al.* 2004). The availability of sites, the partly established production technology (see Ingram & De Silva 2004), and the high quality product provide a basis for Murray cod aquaculture to develop into a significant industry in the future.

Conclusion

Murray cod is an icon of the Murray-Darling River System. It formed one of Australia's first large-scale commercial fisheries, but like many others through-out the world, suffered a significant decline in the 1900s due to over-fishing and environmental degradation. The recovery of Murray cod in some NSW waters over the last decade suggests that improved fisheries and environmental management are having a positive effect. However, the continued poor status of Murray cod in Victoria waters and losses of large numbers from fish kills in some rivers in recent years demonstrate the need for continued vigilance and commitment to the management of Murray cod.

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