Background and Implementation Information for the National Recovery Plan for the Murray Cod *Maccullochella peelii peelii*

National Murray Cod Recovery Team

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This is a Background and Implementation Information document associated with a Recovery Plan prepared under the Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999, with the assistance of funding provided by the Australian Government.

This Recovery Plan has been developed with the involvement and cooperation of a range of stakeholders, but individual stakeholders have not necessarily committed to undertaking specific actions. The attainment of objectives and the provision of funds may be subject to budgetary and other constraints affecting the parties involved. Proposed actions may be subject to modification over the life of the plan due to changes in knowledge.

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Table of Contents

‘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’.

Robert Kearney and Melissa Kildea (2001)

Background Information

Development of Recovery Plan

This Recovery Plan has been developed through a series of steps which followed the species' listing under the EPBC Act in 2003. A workshop to address the management of Murray Cod within the MDB was held in Canberra in June 2004 and attended by a cross section of government and non-government stakeholders and experts (Lintermans and Phillips 2005). The workshop concluded that there are compelling reasons for concern about the future of Murray Cod. This workshop reviewed current knowledge of the history, status, population trends, threats and management responses relating to Murray Cod. The broad expertise of the attendees enabled the development of a list of priority objectives and actions (Appendix 1). These actions link closely to, and are framed by, relevant objectives within the *Native Fish Strategy for the MDB 2003-2013* (Appendix 2). These actions also form the basis of the range of actions identified in this Recovery Plan.

A 'Murray Cod Taskforce' (MCT) was established under the guidance of the Murray-Darling Basin Commission Native Fish Strategy Implementation Working Group (NFSIWG) to provide regular advice through the NFSIWG to the Ministerial Council, the MDBC Community Advisory Committee and the Native Fish Strategy Community Stakeholder Taskforce, on key management issues affecting Murray Cod. Membership of the MCT is drawn from fisheries, conservation agencies, angler and community groups and NRM Boards and CMAs. The MCT has overseen the development of this Recovery Plan and provided extensive comments. The Terms of Reference for the MCT and list of members is provided in Appendix 3. The Recovery Team comprised representatives from each State and Territory agency (see inside cover for members). Most MCT member organisations, together with the major stakeholders involved in recovery of the Murray Cod have roles and responsibilities under the Recovery Plan. It is therefore appropriate that this group adopt a role in the implementation of this for the Recovery Plan for Murray Cod. This could include providing oversight and coordination of implementation of the Recovery Plan. Local implementation arrangements, such as expert/technical working groups, will be formed where required, to facilitate implementation at the regional level, and provide advice to the MCT. The MCT should provide and accept advice from the Commonwealth/MDBC and State agencies.

A series of drafts of the Recovery Plan were prepared by the Recovery Team and initially circulated to the MCT. The next stage was more extensive circulation to State and Territory agencies and interest groups identified in Table 3 in the Recovery Plan, as well as range of Aboriginal groups identified for each State and Territory. A public consultation process followed. While the Recovery Plan has been developed with the involvement and cooperation of a broad range of stakeholders, individual stakeholders have not necessarily committed to undertaking specific actions. The achievement of objectives and the provision of funds will be subject to budgetary and other constraints affecting the parties involved. Proposed actions may be subject to modification over the life of the plan due to changes in knowledge. The suggested authorities involved in participating in and reporting on the achievement of actions is indicative only and needs to be determined within each jurisdiction.

Species Information

Ecological Significance

Although the Murray Cod is well known as a fish, there has been relatively little study of its ecology in the wild, with most information coming from studies of captive animals, or speculated from wild observations. The Murray Cod is the top-order or apex aquatic predator in the Murray-Darling River system (Rowland 2005, Ebner 2006, Baumgartner 2007). In terrestrial ecosystems, top-order predators are usually uncommon to rare in the communities of which they are part. However, at the time of European exploration and settlement of the MDB, the Murray Cod seems to have been remarkably abundant, possibly a reflection of the relatively simple aquatic communities and short food chains in the Murray-Darling, although with an abundant supply of prey items. The sheer numbers of cod present then would have had a

profound impact on food chains and on the aquatic community, although its ecological significance is difficult to quantitatively assess. However, the general principles of fish communities being an essential component of the well-being of river systems, through transportation and cycling of carbon and nutrients, and regulation of trophic levels in aquatic food chains (Gehrke 2000) are especially likely to apply to the Murray Cod. Indeed, its impact is likely to be so substantial that it lead Kearney and Kildea (2001: p. 16) to state: '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'.

Taxonomic Comments

Murray Cod is one of four taxa within the endemic percichthyid genus *Maccullochella*. The other representatives are the Mary River Cod *Maccullochella peeliii mariensis* (endemic to the Mary River system in south-eastern Qld), the Trout Cod *Maccullochella macquariensis* (occurring in the Murray and Murrumbidgee River systems in NSW, ACT, Vic) and the Eastern Freshwater Cod *Maccullochella ikei* (occurring in coastal rivers of north-eastern NSW) (Harris and Rowland 1996). All species and sub-species of *Maccullochella* are considered threatened nationally; Trout Cod, Mary River Cod and Eastern Freshwater Cod are Endangered, while Murray Cod is Vulnerable (EPBC Act).

Murray Cod is most closely related to Mary River Cod, the two taxa being considered subspecies. There are however other taxonomic reviews underway which may further clarify relationships. Murray Cod is similar in appearance to Trout Cod, which has resulted in some confusion in the identification and taxonomic status of both species, especially as the range of both species largely overlapped historically. Although Trout Cod was first described in 1829 and Murray Cod in 1838, it was not until 1972 that the two species were confirmed as being distinct, separate species (Berra and Weatherley 1972). Hybridisation between Murray Cod and Trout Cod has been reported in Cataract Dam (Nepean River New South Wales) where both species were introduced (Wajon 1983; Harris and Dixon 1988), in the Murray River downstream from Yarrawonga Weir, and in a fish hatchery (Douglas *et al.* 1995). The occurrence of hybrids in the Murray River is one of very few cases where hybridisation has been reported in freshwater fish in natural wild situations in Australia.

Legal Status and Conservation Status

The Murray Cod is listed as Vulnerable under the *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act). It is currently considered threatened in Victoria, where it has been assessed as Endangered (DSE 2003) and is listed under the *Flora and Fauna Guarantee Act* 1988 (FFG Act). The species is also a component of the 'Lowland riverine fish community of the southern MDB', a Listed threatened community under the FFG Act. In NSW, the Murray Cod is also a member of three listed 'Endangered Ecological Communities' under the *Fisheries Management Act* 1994: (1) the 'Aquatic ecological community in the natural drainage system of the lower Murray River catchment', (2) the 'Aquatic ecological community in the natural drainage system of the lowland catchment of the Darling River' and (3) 'Aquatic ecological community in the natural drainage system of the lowland catchment of the Lachlan River'.

Murray Cod has suffered a substantial decline in abundance throughout the Murray-Darling River system since European settlement of Australia, although its natural distribution remains largely unchanged. The recommendation for listing Murray Cod under the EPBC Act concluded that the species had declined substantially in numbers, with an estimated historic decline of at least 30% in numbers within the last 50 years, and an estimated maximum Extent of Occurrence of 660 km^2, within which there has been substantial loss and degradation of habitat (TSSC 2001). More generally, native fish populations in the Murray-Darling River system are estimated to have declined to about only 10% of their pre-European abundance (MDBC 2004a). A review of the status of Murray Cod in 2001 prior to its listing under the EPBC Act concluded that 'persistence of the species does not appear to be of immediate concern but the integrity of wild populations and of the ecosystems which support them are seriously threatened' (Kearney and Kildea 2001).

Description

Murray Cod, also known as the codfish, goodo, greenfish and Murray Perch, is a large, heavy-bodied, 'groper-like' percoid fish. Body cross-section varies from somewhat laterally compressed in small or slim specimens to almost rounded in very large specimens. The head is broad and depressed, the snout blunt and rounded, and the mouth terminal and large, with a gape extending to well beyond the level of the posterior border of the eyes. The jaws are about equal in length, although the lower jaw can be slightly longer in large specimens. The eyes are small and dorso-lateral in position. The dorsal profile of the head is concave, then weakly convex from the nape to the short caudal peduncle. The opercula have fleshy margins and two spines, the lower larger and more distinct. The body is covered by very small scales extending to the cheeks, while the snout is naked. The lateral line is indistinct, unbroken and follows the dorsal profile from the opercula to the base of the caudal fin. There are 65–80 scales in series along the lateral line. There is a single very long-based dorsal fin, consisting of an anterior spiny and posterior soft-rayed sections, the sections partially separated by a shallow notch. The caudal fin is large and rounded. The anal fin is short-based and opposite the soft-rayed section of the dorsal fin. The pectoral fins are large and rounded, the upper rays longer than the lower rays. The pelvic rays are inserted in front of the pectoral fins, with the first ray elongated into two filaments.

Colouration is typically olive green to yellow-green dorsally, with black, blue-black, grey-brown to pale green mottling on the dorsal surface, sides and head, often becoming reticulated in large specimens. The sides are usually more yellowish, fading to white or off-white ventrally. Colour pattern extends on to the bases of the dorsal, caudal, anal and pectoral fins, and the caudal, anal and posterior section of the dorsal fin often have off-white to greyish margins. Young fish have larger blotches along their sides that break up with increasing size, and often have a blackish stripe extending from the snout through the eyes to the edge of the opercula. This stripe does not usually persist in individuals longer than about 150 mm (species description from Cadwallader and Backhouse 1983; Harris and Rowland 1996). Murray Cod can grow to a substantial size, reputedly to 1.8 m in length (Whitley 1955) and 113.6 kg in weight (Noble, in Rowland 1989). Most specimens taken are less than 5 kg in weight, and fish greater than 1 m and 40 kg are rarely seen now. There is no known sexual dimorphism.

Distribution

Natural distribution

The Murray Cod is endemic to the Murray-Darling River system in south-eastern Australia, including South Australia, Victoria, New South Wales, Australian Capital Territory and Queensland (Harris and Rowland 1996). The species occurred throughout almost the entire system, with the exception of some of the upper reaches of tributaries, and it still occurs throughout almost all of its historic range, although with some localised extinctions in several upper tributaries.

Introductions

The Murray Cod has been successfully bred in hatcheries for many years, and both hatchery-bred and wild-caught fish have been widely translocated and stocked within and outside its natural range (Lintermans 2005; Pierce 1990; Rowland 1989). The existing policies and guidelines across the Basin concerning introductions of fish are summarised in 'Stockings and Translocations'. Murray Cod populations in some areas, particularly in lakes and impoundments, are maintained by stockings of hatchery-bred fish. Translocations into areas outside its natural range have resulted in extralimital populations becoming established in several locations. The species is present in the Cooper Creek system in Queensland and South Australia and was stocked in 1989-90, although whether it has established breeding populations is unknown (Wager and Unmack 2000). Breeding individuals have been recorded around Longreach (Vanessa Bailey, EPA, Queensland). Elsewhere in Queensland it has been introduced to dams on the Burnett and Fitzroy River systems, although the species does not appear to have become established (M. Hutchison, DPI&F, pers. comm.). In New South Wales it occurs in Cataract Dam in the Nepean River system. In Victoria, introduced populations occur in the Yarra River, Wimmera River and several isolated lakes and swamps in the Wimmera district, most notably Lake Charlegrark. However, some of these lakes (e.g. Booroopki Swamp,

Green Lake, Taylors Lake) periodically dry up and local populations die out. The species has been found in the Light River in South Australia (M. Hammer, pers. comm.). The species was also introduced into Western Australia, but did not establish there (Morrissy 1970). Murray Cod have also been stocked into numerous waters on private property such as lakes and farm dams, where local populations may have established.

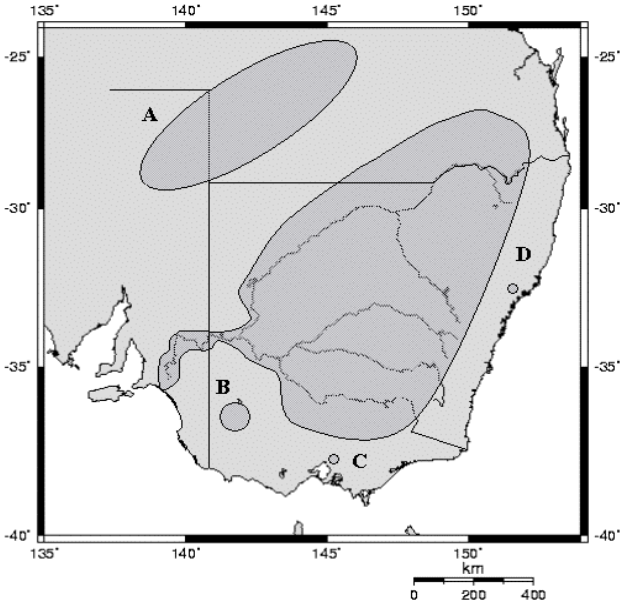

Figure 1. Distribution of the Murray Cod

Letters indicate major extralimital, introduced breeding populations: A = Cooper Creek (SA and Qld)); B = Wimmera Lakes (Vic); C = Yarra River (Vic); D = Nepean River (NSW)

Within its range, the Murray Cod occurs naturally in the following IBRA bioregions (*sensu* EA 2000): Murray-Darling Depression, Riverina, NSW South western slopes, South Eastern Highlands, Cobar Peneplain, Darling Riverine Plains, Brigalow Belt South and Nandewar.

Habitat

The Murray Cod occurs in a range of flowing and standing waters, from small, clear, rocky streams on the inland slopes and uplands of the Great Diving Range, to the large, turbid, meandering slow-flowing rivers, creeks, anabranches, and lakes and larger billabongs, of the inland plains of the MDB. Within these broad habitat types, Murray Cod are usually found associated with complex structural cover such as large rocks, large snags and smaller structural woody habitat, undercut banks and over-hanging vegetation (Dakin and Kesteven 1938; Lake 1967b; Langtry in Cadwallader 1977; Cadwallader 1979; Cadwallader and Backhouse 1983; Harris and Rowland 1996; Koehn 1996, 2006; Rowland 1988a, 2005). The species frequents the main river channel and larger tributaries and anabranches, which are important habitats, and is considered a 'main channel specialist' (Humphries *et al*. 2002). It will use floodplain channels when these are inundated (Koehn 1997, 2006; Koehn and Harrington 2005), but the use of the floodplain proper by adults, juvenile or larvae appears limited (Koehn and Harrington 2005, 2006; King and Koehn unpubl. data). While nursery habitats for post-larval fish have not been identified, juveniles less than one year old have been found in main river channels where it appears they settle at a late larval stage (Koehn and Harrington 2005).

Habitat is critical to the survival of Murray Cod yet to date there are no areas where Murray Cod habitat is protected in its entirety. Similarly, this species is recognised as being susceptible to take (both legal and illegal) but there are no areas where the species is protected from this potential threat. Being a large, long-lived, habitat dependent and highly sought species, Murray Cod is a species which may benefit from protection of its habitat and protection from excessive exploitation of reproductively important components of its population.

Biology and Ecology

Diet

As an apex predator, Murray Cod feed mainly on fish and large crustaceans (Ebner 2006, Baumgartner 2007). They are carnivorous, with a diet including a wide variety of aquatic organisms such as spiny crayfish, yabbies and shrimps, as well as fish including Goldfish, Redfin, Carp, Bony Herring (and occasionally, Silver Perch and Golden Perch), aquatic insects and bivalve molluscs (Cadwallader and Backhouse 1983; Harris and Rowland 1996; Rowland 1988a). Diet changes with age and size. Murray Cod larvae consume zooplankton, particularly cladocerans and copepods (Koehn unpubl.; Rowland 1992), and begin feeding on aquatic insects at 15–20 mm in length (Kailola *et al.* 1993). Adult cod consume larger prey items, occasionally including vertebrates such as frogs, reptiles and birds (Rowland 1988a).

Behaviour

Murray Cod are most active during spring and early summer and appear to be more active at night (Koehn unpubl. data). During the day they normally seek shelter around logs and other debris, the resting places appearing to form the focal point of their territories (Kailola *et al.* 1993; Harris and Rowland 1996; Koehn 1996). Young Murray Cod become territorial and behave aggressively towards other cod from 40–50 mm in length, and adults are considered solitary and highly territorial (Cadwallader 1979; Cadwallader and Backhouse 1983; Cadwallader and Gooley 1985), although anglers report the capture of several similar size cod from the one location, indicating aggregations may occur (Kearney and Kildea 2001).

Age and Growth

Age and growth rates have been documented for several lake and river populations (Anderson *et al.* 1992; Gooley 1992; Rowland 1985, 1988a, 1998b). Newly hatched larvae are 6–9 mm in length, have a large yolk sac, and begin feeding about 10 days after hatching, at about 20°C. Growth rate varies considerably between locations and seasons, and is influenced by temperature, habitat and food availability. In New South Wales rivers, growth has been estimated as 23 cm and 0.2 kg, 35 cm and 0.8 kg, 50 cm and 2.0 kg, 58 cm and 3.5 kg, and 64 cm and 5.0 kg after one to five years respectively. At over five years of age, fish grow at between 1.0–2.5 kg per year, with fish from impoundments tending to grow faster than fish from rivers, and Murray River fish are heavier per unit length than those from the Darling River (Rowland 1988a). Murray Cod reach sexual maturity at 4–6 years of age (rarely earlier in some populations) and at minimum weights of about 2 kg for females and 0.7 kg for males (Cadwallader and Gooley 1984; Gooley *et al.* 1995; Rowland 1988b). In southern waters, feeding activity (and therefore growth rate) is reduced by low water temperatures during winter, and fish probably mature later and at a larger size than fish in more northern waters (Glen Wilson, UNE, unpublished data). The Murray Cod is among the most long-lived Australian freshwater fish, with a 1.4 m long, 43 kg fish being 47 years old (Anderson *et al.* 1992). A 1.27 m fish collected from the Murray River in 1996 downstream of Yarrawonga was ages at 49 years (Greg Sharp, DPI, pers. comm.). It is possible that some of the largest specimens taken in the past may have been much older, with an age estimate of the largest cod ever caught (113.6 kg) being 74–114 years old (Rowland 1988a).

Reproduction

Aspects of the reproductive biology of Murray Cod have been reported from a range of hatchery studies and some recent studies and observations in the wild (Lake 1959, 1967; Langtry, in Cadwallader 1977; Cadwallader *et al.* 1979; Cadwallader and Gooley 1984; Rowland 1983a,b, 1985, 1988; Gooley *et al.* 1995; Humphries 2005; Koehn and Harrington 2005, 2006. The species has an annual reproductive cycle and a relatively short, defined breeding season. In captivity, Murray Cod form pairs and spawn in spring-summer, in response to rising water temperatures of 16.5–23.5°C, with most spawning at around 20°C (Cadwallader *et al.* 1979; Cadwallader and Gooley 1984; Gooley *et al.* 1995; Rowland 1985, 1998a). In the wild, spawning has been shown to occur at temperatures as low as 15°C (Humphries 2005, Koehn and Harrington 2006). Reproduction appears to be largely dependent upon water temperature, with flooding or a rise in water level apparently not required to initiate spawning (Rowland 1983a,b, 1988; Cadwallader and Gooley 1985). Spawning in rivers has been shown to occur regularly each year despite a range of flow conditions (Humphries 2005, Koehn and Harrington 2006). Spawning commences in early spring in the northern part of its range, but may not commence until late spring or early summer in the southern part of its range (Rowland 1988b).

In a study of the biology of Murray Cod in Lake Charlegrark (Vic), the smallest ripe male was found to be 5–6 years old, 440 mm long and 1.4 kg in weight, while the smallest ripe female 6–7 years old, 485 mm long and 2.3 kg in weight (Cadwallader and Gooley 1984).

The number of eggs laid is generally related to the size of the female, with females 2–3 kg producing 6–10,000 eggs, at 5 kg producing around 40,000 eggs, at 23 kg around 90,000 eggs, 110, 000 eggs at 33 kg (Stuart and Koehn unpubl. data), and up to 200,000 eggs in very large fish (Kailola *et al*. 1993; Lake 1959, 1967a; Rowland 1988b). The eggs are 2.5–3 mm in diameter, swelling to 3–4 mm in diameter when water-hardened, adhesive, demersal, opaque and pale amber in colour (Dakin and Kesteven 1938; Lake 1967; Cadwallader and Backhouse 1983; Rowland 1983a,b). The average diameter of the yolky part of the egg is 2.5 mm and there is usually one large and many small oil globules present. Eggs are laid on a hard substrate such as large structural woody habitat, rocks and clay surfaces, while in ponds and dams, captive cod have spawned inside hollow objects such as concrete pipes and metal drums, on fallen timber and directly on the substrate (Cadwallader *et al.* 1979; Cadwallader and Gooley 1984; Gooley *et al.* 1995; Rowland 1988a). Murray Cod will excavate saucer-shaped depressions in the substrate, the bigger the fish the bigger the depression. It is not certain if these are only resting sites or are used for spawning. The finding of large depressions in the substrate of natural waters inhabited by Murray Cod has led to the belief that cod use the depressions as spawning sites, similar to the nests made by Freshwater Catfish *Tandanus tandanus*. Large numbers of these depressions were seen on mud banks in the Murrumbidgee River in the late 1940s in October, and it was speculated that these were Murray Cod 'egg pans' (Langtry, in Cadwallader 1977). The eggs are typically deposited in a layer one-egg thick, and the area covered by an egg mass laid on the substrate in a small dam at Snobs Creek research facility measured about 45 cm by 35 cm (Cadwallader and Backhouse 1983). The eggs are guarded by the male fish and hatch after 4–13 days, depending on temperature, with hatching occurring within 5–7 days at temperatures of 20–22°C, and being mostly completed 2–3 days after commencement (Cadwallader *et al.* 1979; Cadwallader and Gooley 1984; Kailola *et al*. 1993; Rowland 1988b, 1998, 2005). Spawning generally occurs in a single event, although multiple spawnings and the spawning of male fish with multiple partners have been recorded (Brett Ingram, DPI, and Steve Thurston, DPI NSW, pers. comm., Rourke et al. 2009).

Recruitment

While spawning in Murray Cod apparently does not require flooding, recruitment success appears to be strongly linked to river flow, with good year classes in some rivers coinciding with a rise in water level or flooding at or soon after spawning (Rowland 2005; Ye *et al.* 2000). Recruitment success is likely to be linked to timing, duration and water quality, especially temperature, of the flows, and flooding in spring appears to provide optimum conditions for survival and recruitment of larvae and juveniles in rivers (Kearney and Kildea 2001; Rowland 1985, 1989, 1998a). King *et al*. (2007) found increased recruitment of 0+ Murray Cod in the year following flooding, although distinct correlations between flows and year classes in the mid reaches of the Murray River are less certain (Nicol and Koehn, unpubl. data).

Migration and movements

The Murray Cod have been considered to be a generally non-migratory and sedentary species (Cadwallader and Backhouse 1983; Reynolds 1983; Kailola *et al*. 1993; Humphries *et al*. 1999 Cadwallader 1977). This is generally so for part of the year when movement is limited and site fidelity high. Both lake and river fish have been shown to undertake substantial long-distance movements prior to spawning (Koehn 1996; 2006; Koehn and Nicol 1998), which appears to be a spawning migration. Fish tagged in Lake Mulwala (Murray River NSW) moved up to 100 km into the Murray and Ovens River systems prior to spawning, before returning to their original territory several weeks after spawning. Homing occurred for about 2/3 of fish. Upstream movements may coincide with rising water levels, although some movement occurred without flooding. Individual fish commenced upstream movement from late winter to late spring, so not all fish in the same population move at the same time. Variation in movement patterns occurred between individual fish and larger movements for river fish were restricted to fish > 650 mm in length. Lake fish also moved further upstream than river fish (Koehn 2006). Several land-locked, lake-dwelling populations of Murray Cod are known, so a spawning migration is not essential for spawning.

Larval Murray Cod initially remain near the spawning site, usually forming large clumps. After several days the clumps disperse, and the larvae have a nocturnal drifting stage, where they

rise in the water column and drift with the current (Humphries *et al.* 2002; Koehn and Harrington 2005, 2006), which probably aids in dispersal away from the spawning site. Drifting larvae range from 9.5-15mm and may occur over up to 10 weeks with a peak abundance in November. Abundances have been best accounted for by three variables - year, day length and flow in the previous seven days (Koehn and Harrington 2006).

Decline and Threats

The Murray Cod remains widely distributed throughout the Murray-Darling River system with only a small decline in total range, although it has undergone an extensive decline in abundance since European settlement of Australia, especially in the last 70 years (Cadwallader and Gooley 1984; Harris and Gehrke 1997; Rowland 2005), and there have been some recent localised extinctions (Koehn *et al*. 1995). An indication of the extent of the decline can be gauged from historical and anecdotal records, and from the commercial fishery. Early records dating from the early times of European settlement indicate that Murray Cod were abundant, and of large size, in the Murray-Darling River system. The explorer John Oxley, in 1817, recorded that the Lachlan 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 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'* (cited in Rowland 2005). There are similar enthusiastic historical reports of captures of abundant large cod from other rivers in the system (Rowland 1989, 2005). The commercial fishery for cod developed in the mid to late 1800s, and early fishery reports noted the large numbers and size of cod present. Catches apparently peaked in the early 1900s, then declined, then reached a smaller peak in the early 1950s, when up to 150 tonnes in South Australia and 140 tonnes in New South Wales was caught per year (Dakin and Kesteven 1938; Rowland 1989; Kailola *et al.* 1993; Ye *et al*. 2000). Catches declined steeply soon after, but continued at a very low level for about another 40 years. There was also a large reduction in both the number of commercial fishers and the area available for commercial fishing, and the last commercial wild fishery for Murray Cod finally closed in 2003. However, the commercial catch has now largely been replaced by the recreational fishery catch (Kearney and Kildea 2001).

In Victoria, the species has undergone a decline in range and a substantial decline in abundance in all major tributaries of the Murray River (Cadwallader and Gooley 1984; Koehn 2005a). It is now rare or absent from the mid-reaches of the Goulburn, Campaspe and Loddon rivers, and could be considered common only in the lower reaches of these rivers. The species was deemed to be locally extinct in the Mitta Mitta River for 100 km downstream of Lake Dartmouth following construction of the dam because of cold water pollution (Koehn *et al*. 1995), and the Broken Creek population was subject to a major fish kill in February 2002 (Koehn 2005a). Recovery from this fish kill has been limited to date. Fish kills have impacted several populations in the Ovens River and Goulburn-Broken River system in recent years (Koehn 2005a). Victoria is the only State or Territory that has listed Murray Cod as a threatened species (Endangered).

In New South Wales, Murray Cod had also declined in abundance, and there were apparently some local extinctions in several rivers and upper tributaries in northern NSW in the early 1900s (Faragher and Harris 1993; Rowland 1989, 2005). The population in the Molonglo River was eliminated by heavy metal pollution from the Captains Flat mines in the 1930s and 1940s (Lintermans 2002). A survey in 1996 failed to record any Murray Cod at 20 randomly selected sites on the Murray River, and detected cod at only seven of 20 randomly selected sites on the Darling River. Murray Cod populations were considered fragmented and patchy, and their overall abundance worryingly low (Harris and Gehrke 1997). However, since that time there appears to have been a small recovery in cod stocks in NSW. Translocation and stocking of cod by local anglers has led to the re-establishment of populations in northern tributaries (Rowland 2005), while anglers report good captures in recent years (cited in Rowland 2005, R Loats VRFish pers. comm. 2006), and fisheries surveys over the last 10 years indicate an increase in Murray Cod populations across NSW (Gilligan unpubl. in Rowland 2005). The apparent increasing abundance in some areas of NSW may be attributable to good natural recruitment in flood years and fishing regulations, and there has been speculation that increasing and declining cod stocks possibly occurred in cycles (Rowland 2005). While Murray Cod remain relatively common in many areas in NSW, there is concern about altered and possibly unstable population structure. In the Murray River between Tocumwal and

Yarrawonga, an area that is heavily fished and cod are locally common, the population is heavily skewed to small, pre-breeding size fish (<50 cm length). Numbers of fish in the 50–90 cm size range (prime breeding range) are much lower than would be expected to occur in a natural population, leading to the possibility of an unsustainable population structure (Nicol *et al*. 2005). Recreational anglers are currently reporting catches of large Murray Cod from this river reach with fish from 10-25kg being recorded (Rob Loats, VRFish, pers. comm. 2007).

Murray Cod remain distributed throughout their historical range in SA and Qld. No cod habe been recorded from the Paroo River in recent years (SRA and other DPI&F surveys) but local fishermen did report them to be present up to the 1980s. Possibly the arid nature of this water means cod are more susceptible to overfishing in the few permanent waterholes. In SA, while there has been a decline in numbers from early levels (Kearney and Kildea 2001), a Fisheries Assessment Report in 2000 indicated a gradual increase in stocks following a moratorium on take between 1990 and 1993. Size composition data indicated that there was a small number of strong size classes, which corresponded to the floods in 1989 and the early 1990s (Ye *et al*. 2002). A more recent Fisheries Stock Status report (Ye and Zampatii 2007) determined that there is little indication of strong recruitment of the species since 1994. In the ACT, at the upper limit of the Murray Cod's distribution, the species is locally extinct in the upper Molonglo River (Lintermans 2005), but still occurs as stocked populations in the lower Molonglo and elsewhere within its historical range.

The recommendation for listing Murray Cod under the EPBC Act as Vulnerable concluded that the species had declined substantially in numbers, with an estimated historic decline of at least 30% in numbers within the last 50 years, and an estimated maximum Extent of Occurrence of 660 km^2, within which there has been substantial loss and degradation of habitat (TSSC 2001). More generally, native fish populations in the Murray-Darling River system are estimated to have declined to about only 10% of their pre-European abundance (MDBC 2004a). While there are still some good local populations, at a national scale the Murray Cod has declined, populations are fragmented and the species is under threat. A review of the status of Murray Cod in 2001 prior to its listing under the EPBC Act concluded that 'persistence of the species does not appear to be of immediate concern but the integrity of wild populations and of the ecosystems which support them are seriously threatened' (Kearney and Kildea 2001).

There is a significant role for large-scale monitoring to establish current levels of abundance across the range of Murray Cod and to provide a base-line for continued monitoring to determine population trends. It is hoped that some of this data will become available in some areas through data contributed through surveys conducted for the Sustainable Rivers Audit. Due to the limitations in the numbers of sites for this widespread environmental monitoring, additional survey sites may need to be considered for Murray Cod in some areas.

The threats to Murray Cod have been summarised in several recent publications (Koehn 2005b; Lintermans *et al*. 2005; Rowland 2005; TSSC 2001). The Murray Cod has declined throughout the Murray-Darling River system since European settlement, from causes including habitat loss and degradation, pollution, barriers to fish passage, flow regulation, cold water releases and fishing. Some State legislation includes provision for the listing and management of threatening processes relevant to aquatic and riparian habitats and thereby Murray Cod. Those listed in Victoria and NSW are summarized in Appendix 5. No threatening processes are listed under ACT, Qld or SA legislation.

Environmental changes are probably the main cause of the substantial decline in abundance of Murray Cod. Rowland (2005) suggested the decline of Murray Cod in NSW had different causes at different stages. Overfishing by the commercial fishery between the late 1800s and 1930s caused the initial decline, then chemical pollution from agriculture in the early 1900s, predation by and competition from Redfin Perch *Perca fluviatilis* in the 1950s and 1960s; and reduced survival and recruitment of larvae and juveniles due to the effects of river regulation since the 1950s. Current recreational fishing pressure in some areas may be leading to unstable population structure (Nicol *et al*. 2005), while major kills of adult Murray Cod, apparently from poor water quality, are still occurring in core parts of its range (Koehn 2005a). Management issues such as competing interests for water, a lack of 'ownership' of and lack of effective legal responsibility for, Murray Cod, and the inadequate response to fish kills, especially in identifying causes and initiating remedial action, are also considered threats (Koehn 2005b; Sinclair 2005a). The lack of key biological information such as assessment of

recruitment, mortality of different age classes, and the level of take, especially of large adults is hindering effective management for recovery (Koehn 2005b).

Reductions in native fish populations result from the interactions between inadequate flows, poor water quality, poor habitat and predation (Cottingham *et al*. 2001). In some cases, the actual threat may have ceased (e.g. commercial fishing), but its consequences are still being felt. In other cases, such as river regulation, the threat is sustained and on-going. Other threats are erratic and episodic, such as fires and deteriorating water quality causing fish kills. The cumulative impact of many small or low risk threats (e.g. fish kills, angler take, low water temperatures or lack of flooding reducing breeding success) can combine to further reduce population numbers and increase localised extinction risk through population fragmentation and incremental loss. Isolated populations are most at risk, and fragmentation of habitat reduces likelihood of recolonisation. Population fragmentation and incremental population loss decreases the chance of being able to recolonise after catastrophic events. Deviations from sustainable population structures such as through the loss of an over proportion of breeding adults, for example, can add risk to long-term population viability. The Murray Cod is a slow-growing, long-lived territorial predatory species at the top of the food-chain. For a species with these life cycle characteristics, localised extinctions may continue to occur after the primary cause of decline has ceased to operate.

The *Native Fish Strategy for the Murray-Darling Basin 2003-2013* (MDBC 2004a) lists eight key threatening processes affecting native fish in the Murray-Darling River system, all of which are likely to be affecting Murray Cod populations to varying degrees. The major current and suspected threats impacting on Murray Cod are detailed as follows:

Flow Regulation

Flow regulation occurs where water is impounded and removed, or removed directly, from a river system. Many rivers in the Murray-Darling Basin have dams and weirs that regulate flow, and a substantial amount of water is abstracted from the Murray River system annually (10,800 GL/year) (Lintermans and Phillips 2004), through collection in impoundments, diversion through irrigation channels and direct pumping from rivers, largely for agricultural use. Flow regulation has greatly altered the natural flow regime of rivers. The consequences of this impoundment and removal of water from the river systems includes a reduction in flow rate and volume, extended periods of critical low flows and no flow, loss of flow variation and seasonality and loss of low to medium flood events. Upstream from the dam wall, there is permanent flooding, reduced flow and high water. In extreme cases the natural flow regime is now reversed, with low winter flows in rivers as water is contained within impoundments, and high flows in summer as water is released for irrigation. River regulation has also altered both the quality and availability of floodplain habitats such as backwaters and billabongs, due to reduced flooding. Indeed, there is evidence that the great River Red Gum forests along the Murray River system are under severe stress due to flow regulation.

The impact of river regulation and altered flow regimes is implicated in the decline of many Murray-Darling River system fish species (MDBC 2004a). Most debates regarding the importance of floods and a natural flow regime for native fish involves the contribution flow makes to conditions that enhance recruitment. While the applicability of the Flood Pulse Concept (Junk *et al.* 1989) to Australia fishes, including Murray Cod, has recently been questioned (Humphries *et al.* 1999), it has been suggested that recruitment success of Murray Cod is directly linked to river flow, with a rise in water temperature and flood events being key triggers for spawning and survival of young fish (Kearney and Kildea 2001; Ye *et al.* 2000; Rowland 1998). Reductions in flooding may be a major cause for the decline of Murray Cod as a result of changes in suitable conditions for spawning and larval recruitment (Rowland 1989). The impact on the native fish community in the Murray-Darling River system is thought to have been substantial (MDBC 2004a). Reduced flows also affect the ability of fish to migrate, especially those species that undertake pre- or post spawning movements. Reduced flooding reduces the amount of habitat available, especially for the smaller species. Cooler water temperatures downstream from dams may inhibit spawning and slow growth. Dams and weirs also act as barriers to fish movement. The potential for direct loss of native fish into irrigation channels and through pumps is unknown, but could potentially be relatively high (Koehn *et al.* 2004; Koehn 2005b; Lintermans and Phillips 2004). This is a view supported by a preliminary

investigation of the movements of tagged fish in Lake Nagambie (Goulburn River, Vic) (T. Ryan, pers. comm.). Despite the use of fish exclusion devices elsewhere in the world to prevent fish loss to irrigation systems, and the heavy reliance on irrigation water in the MDB, no exclusion devises have been fitted to irrigation offtakes to prevent fish loss (Blakeley 2004). River regulation has played a significant role in the decline of Murray Cod since the mid-1950s as the optimum conditions for survival of Murray Cod are much less frequent (Rowland 1985, 1989).

Habitat degradation

Habitat degradation comes about through a variety of causes. Desnagging involves the removal, lopping or realignment of this structural woody habitat, to facilitate navigation, improve water flow, mitigate floods and protect assets such as bridges from flood damage due to debris jams forming. Murray Cod are dependent on large structural woody habitat (snags: fallen tree trunks and branches, particularly River Red Gum *Eucalyptus camaldulensis*) for habitat and shelter. The removal of woody habitat has been widespread in Murray-Darling Basin rivers, particularly in lowland reaches over a large number of years (Gippel *et al.* 1992; Mudie 1961; Phillips 1972; Treadwell *et al.* 1999). Desnagging has undoubtedly reduced or destroyed prime habitat for adult Murray Cod, and has also led to fragmentation of remaining available habitat. While desnagging as a regular activity has now largely ceased (except for specific instances where infrastructure such as bridges may be at risk), there is still considerable manipulation of snags through realignment, lopping and other river 'improvement' activities, and timber is continually removed from dry floodplain channels that are used by cod when the channels carry water (S. Nicol DSE-ARI pers. comm.). The cumulative effects of many manipulations over time is probably quite substantial, and the long-term affects of widespread desnagging may still be impacting Murray Cod populations. Reinstatement of woody habitat is now recommended as a priority action for river restoration (MDBC 2004a), and our understanding of its effects and fish-habitat relationships is increasing (Nicol *et al.* 2002).

Increased siltation through runoff after events such as land clearing and wildfires can have a major effect on isolated or stocked populations. In upland cod populations where cover is often provided by boulder or other hard substrate diversity and snags are naturally less abundant, sedimentation removes significant cover. Extensive wildfires in south-eastern Australia in the summer of 2003 burnt through several areas in the ACT and Victoria, and large amounts of sediment are now flowing into streams. An extensive fish kill occurred in the Buckland and Ovens Rivers (Vic) in March 2003 (J. Lyon DSE-ARI pers. comm.) after heavy rains fell over the fire area and washed enormous amounts of sediment and ash into the system. The infilling of undulations and holes by sedimentation may also impact on cod habitats and could blanket spawning substrates. Deposited sediments may also affect the abundance of food items such as plankton and insects associated with aquatic vegetation. Removal of riparian vegetation leads to reduced shelter, food and timber input into rivers and causes bank instability, leading to erosion and increased sedimentation. River regulation can also reduce habitat availability. Reductions in riparian vegetation result in reduced organic inputs including woody habitat (Hynes 1970). Incremental changes to habitats and changes to ecosystem processes, such as changes in overall river productivity (perhaps caused by a change in water temperature or nutrients trapped by dams) (McCully 1996), can indirectly and gradually affect fish populations.

Lowered Water Quality

Lowered water quality can be caused by altered flows through diversion, impoundment or sustained dry periods reducing run-off. Consequences include excessively raised or lowered water temperatures, reduced dissolved oxygen levels, concentration of nutrients and environmental contaminants. Nutrient run-off from urban and agricultural areas can cause increased growth of phytoplankton, initiating plankton blooms and reducing oxygen levels. Fish kills can result from these conditions, and have become a depressingly regular feature in recent years. There were at least 21 fish kills in the Goulburn-Broken catchment (Vic) alone from 1998–2004 (Ecos 2004) while in New South Wales there were at least 34 fish kills per year between 1986–1996, with the real figure estimated to exceed 60–80 per year (Lugg 2000). Recent major fish kills involving Murray Cod occurred in Broken Creek (Vic) in 2002, Ovens River (Vic) in 2003, Goulburn River (Vic) and Darling River (NSW) in 2004 (data from Koehn 2005a). At least 3000 adult Murray Cod were killed in the Darling River kill, described as 'the

biggest cod kill in history' (Sinclair 2005a). Suspended sediment, low oxygen levels, herbicides and altered water temperatures have all been suggested as possible causes of recent kills of thousands of native and introduced fish species, including large numbers of Murray Cod (Koehn 2005a). These kills have probably been the result of a number of factors, exacerbated by extremely low (or no) flows, or sudden releases from dams of high temperature and low dissolved oxygen water, and have highlighted the fact that water quality problems remain a threat to this species. Modelling of the impact of the Darling River fish kill on the Murray Cod population and options for management indicates that it will take decades for the cod population to recover, and will be extremely costly (Koehn 2005a). However recent compilation of survey data indicates populations in the lower Darling River appear to be in good condition (Gilligan, NSW DPI, pers. comm.).

While such kills provide a graphic reminder of the critical impact of water quality changes, non-critical changes are more common and may have greater overall impacts. High turbidity and salinity may also have adverse physiological or behavioural effects. Stratification may occur in pools due to temperature or salinity gradients, resulting in de-oxygenated, saline bottom layers (Anderson and Morison 1990). Increased salinity in the Murray-Darling Basin is a major problem causing extensive degradation in some areas. Salinity levels in the rivers and lakes vary widely, and the adults of many native fish species have at least a short-term tolerance to moderate to high salinity levels. However, early life history stages (e.g. eggs, larvae) are more sensitive to elevated salinity levels, and the long-term effects of sub-lethal levels of salinity on all life stages are unknown. Chotipuntu (2003) predicted that salinities above 0.34g/L would result in significant impacts on Murray Cod. Elevated salinity levels may also affect food sources such as invertebrates, algae and macrophytes, consequently affecting habitat complexity and quality.

Water released from the bottom of large reservoirs may be up to 7–12°C cooler than ambient river water temperatures, especially over summer (Cadwallader 1978). Cold-water pollution from low-level releases from dams has been estimated to impact on at least 2800 km of waterways in the MDB (Ryan *et al.* 2003), and this impact has been significant on species such as Golden Perch and Murray Cod (MDBC 2004a; Ryan *et al.* 2003). Reduced water temperatures may impair spawning, egg and larval survival, swimming speeds, feeding and growth rates, and favour potential predators and competitors such as the introduced Redfin Perch. Murray Cod spawn at around 20°C. Juvenile Murray Cod held at 24°C grew almost twice as long and 3.5 times as heavy as fish held at 13°C over a 3-month period (Ryan *et al.* 2003). Cold water pollution from low level outlets on dams may lead to localised extinctions downstream of large dams where water consistently fails to reach temperatures required for spawning of some species such as Golden Perch and Murray Cod. The Goulburn River downstream from Lake Eildon is considered heavily stressed (EPA 2004), with cold water pollution a major contributor. Murray Cod have become locally extinct in the Mitta Mitta River downstream of Lake Dartmouth since construction of the dam, most likely due to cold water releases (Koehn *et al*. 1995, Todd *et al.* 2005). It is unknown whether recent reports of captures of Murray Cod in the lower Mitta Mitta River are from resident fish of fish migrating from Lake Hume. Water temperature and population modelling indicate that cold water releases from Lake Hume are likely to have detrimentally affected Murray Cod populations in the Murray River downstream and remediation of this threat is likely to assist in rehabilitation of Murray Cod populations (Sherman *et al.* in review).

The input of pollutants and toxins to rivers may directly poison fish. Heavy metal poisoning from the Captains Flat mines caused the local extinction of Murray Cod from the Molonglo River in the ACT (Lintermans 2002). Declines and local extinctions in northern NSW in the early 1900s have been linked to regular fish kills caused by agricultural chemicals (Rowland 2005). Herbicide use is widespread in the irrigation channel system in Victoria to keep them free of weeds, but this causes regular fish kills, including of Murray Cod (EPA 2004; Sinclair 2005a), which may be a substantial threat given the magnitude of fish loss to irrigation channels (Lintermans and Phillips 2004). Impacts of lesser known chemicals such as hormones from sewage effluents and their impact on fish breeding and sex rations are unknown.

Barriers

Barriers to fish movements include dams, weirs, culverts, levee banks and areas of unsuitable habitat, high flow or turbulence. There are more than 3600 structures that can impede fish movements in the Murray-Darling Basin (MDBC 2004a). Such barriers limit the ability of migratory fish species to complete their life cycle, and, even for non-migratory species, can limit the ability to colonise or recolonise suitable habitat, and can reduce gene flow by fragmenting populations. Barriers may also cause physical injury and/or mortality to drifting eggs and larvae, and may cause premature settling out in low flow areas immediately above barriers, subjecting them to unsuitable conditions reducing survival. Barriers have been recognised as a major threatening process operating throughout the Murray-Darling River system (MDBC 2004a), and in many coastal waterways in eastern and southern Australia. Recent research has provided a greater understanding of the movement of Murray Cod, with larvae having a nocturnal downstream drifting stage and some adult cod making substantial upstream and downstream movements of several hundred kilometres (Koehn 1996; Koehn and Nicol 1998; Humphries *et al.* 2002; King 2002). Barriers may have a major impact on cod populations, interfering with pre and post spawning movements, and fragmenting and isolating populations from one another, leading to problems such as genetic drift and loss of genetic variability. A major program is underway in the Murray River system to facilitate fish passage past barriers, which should be of substantial benefit to the native fish of the Basin, including Murray Cod. However, fishways facilitate predominantly upstream movement, and downstream movement may be a problem (Lintermans and Phillips 2004).

Alien Species

Eleven alien fish species are now established in the Murray-Darling River system (MDBC 2004a), with Carp *Cyprinus carpio*, Redfin Perch *Perca fluviatilis,* Goldfish *Carassius auratus* and Eastern Gambusia *Gambusia holbrooki* the most widespread. Any impact on Murray Cod from these alien species is likely to occur through a range of mechanisms including predation, competition, habitat alteration and spread of diseases and parasites. Carp receive a considerable amount of public attention and are often blamed for many of the ills of the river, such as poor water quality. Recent reviews of carp introduction and impact (Koehn *et al.* 2000; Koehn 2004) indicate that the Carp is a typical invasive species, which is resilient and well-adapted to exploiting riverine environments that are already degraded. Carp now comprise a majority of the fish biomass in the Basin (Harris and Gehrke 1997), and may comprise up to 90% of the fish biomass at some locations in the Murray River. In the recent Pilot Sustainable Rivers Audit, Carp were the most widespread species recorded, occurring at 63 of the 92 assessment sites across four river valleys (MDBC 2004c). Recent surveys in NSW indicate that Carp now inhabit about 77% of NSW waterways, and a further 2% are also likely to be infested (Graham *et al.* 2005). The species has continued to disperse throughout the inland waterways; in the MDB only some upper catchment areas are free of Carp.

Despite public opinion, there is no scientific evidence that increases in carp have affected cod numbers (Koehn *et al.* 2000). At high densities Carp may increase turbidity and reduce aquatic vegetation through their feeding habits, reducing habitat for native species.

There is some correlation between high numbers of alien fish, especially Carp and Redfin Perch, and low numbers of native fish including Murray Cod (Rowland 2005). The recent apparent increases in cod number in NSW coincide with historically low numbers of Carp and Redfin Perch. Predation by and competition with Redfin Perch in the 1950s and 1960s may have been a contributing factor to the decline of Murray Cod in the southern part of MDB during that time (Rowland 2005). Although Carp may compete with Murray Cod for space, there is no evidence for any other form of competition between Murray Cod and Carp, and young Carp may provide a source of food for Murray Cod. Effects of other species that can reach very high densities, such as Eastern Gambusia and Oriental Weatherloach *Misgurnus anguillicaudatus*, are not known. Serious predation by Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss* on Murray Cod is considered unlikely due to limited overlap in the habitats of these species (Koehn 2005b). Alien species are also suspected of introducing a number of parasites and diseases to Australia (see diseases section below). However, while the impact of alien species is probably substantial, in some instances it can be difficult separating

this from the other threatening process operating, especially the impact of flow regulation and the consequences for native fish habitats.

Exploitation

Commercial Fishing

Exploitation of Murray Cod has occurred through both commercial and recreational fishing. The species was once common enough to support commercial fisheries, based mainly in Murray and Murrumbidgee rivers, which developed in the mid to late 1800s (Dakin and Kesteven 1938; Kailola *et al*. 1993; Kearney and Kildea 2001; Reid *et al*. 1997; Rowland 1985, 1989, 2005; Ye *et al*. 2000). The big operators used paddle-steamers as fishing boats, and Murray Cod dominated the catch. Total catch peaked in the early 1900s, but by the 1930s had declined to unprofitable levels for the big operators, although a number of smaller operators continued fishing (Pollard and Scott 1966; Whitley 1937). There was a smaller peak in the fishery in the 1950s, when almost 300 tonnes of Murray Cod per year was caught in NSW and SA, followed by a sharp decline in the commercial catch and a major decline in abundance of cod between 1955 and 1964 in NSW and SA (Reynolds 1976; Rowland 2005). Commercial fishing continued for another 40 years, but the catch declined to less than 10 tonnes/year in NSW in the 1990s. Concern over declining native fish stocks led to the closure of the commercial fisheries by 2003. Murray Cod populations would have been very susceptible to commercial fishing on this scale, and the early decline was caused primarily by overfishing (Reid *et al.* 1997; Rowland 1989, 2005). There has been a noticeable recovery in year classes of Murray Cod and other native fish species since the cessation of commercial activity in South Australia (Ye pers. comm.).

Recreational Fishing

Murray Cod is considered a premier freshwater angling species, and there is heavy recreational fishing pressure in virtually all of its range. Angling pressure is higher during the open season week and during long weekends and Easter periods (Rob Loats, VRFish, pers. comm.). Estimated total legal catch of Murray Cod is considerable. Using data from the National Recreational and Indigenous Fishing Survey, in a 12 month period from March 2000 an estimated 106,000 cod weighing 216 tonnes were caught and retained, while another 368,000 cod were caught and released (Park *et al*. 2005). The previous commercial catch has now largely been replaced by increased take by recreational anglers. An expanding recreational fishery was probably responsible for a decline of cod numbers in central and northern NSW rivers in the 1970s and 1980s (Rowland 2005), while Harris (2005) cited over-harvesting is one of the current 'greatest burdens'. The heavy fishing pressure on some sections of the Murray River is likely to be impacting on population structure of Murray Cod (Nicol *et al*. 2005). In the reach between Tocumwal and Yarrawonga, angler take of fish at 50 cm (the minimum legal size) and above was an estimated 32%, and fish larger than 50 cm are rare, given the large number of fish in smaller size classes. In Lake Mulwala (a large impoundment on the Murray River upstream from Yarrawonga), considered a premier Murray Cod fishery, fish caught in fishing tournaments averaged only 46–50 cm in length, with few fish taken in larger size classes (Park 2005). Although the Lake Mulwala population was considered to be self-sustaining (Park 2005), the removal of such a high proportion of size classes above 50 cm (likely to be of prime breeding age) may have severe impacts on population structure, and may not be sustainable for some populations, leading to population instability or crashes (Nicol *et al.* 2005). Recent radiotracking programs for Murray Cod have indicated high numbers may be taken by anglers e.g. 19% of tagged fish (3 of 16 fish) taken from the Macintyre River near Goondiwindi (Andrew Berghius, DPI, pers. comm.) and 15% of tagged fish (5 of 32 fish) taken in the first year of monitoring in the Mullaroo Creek (Steve Saddlier, DSE-ARI, pers. comm.). This information comes from verified angler returns. The numbers of other fish potentially lost through illegal take is unknown.

There is also concern that the current minimum size of 50 cm does not allow cod to reach breeding age and breed at least once before being at the risk of capture by anglers and removed from the population. Some females reach maturity at age 4, but most reach maturity at age 5 (Koehn and O'Connor 1990), while some fish at age 3 and 4 (generally pre-breeding age) are 50 cm long or larger (Anderson *et al*. 1992, Nicol *et al.* 2005), which suggests that 50

cm minimum size may be too small for some fish to breed. Some experienced fishers do target larger fish in the 20–40 kg size range (Rowland 2005), although an increasing number of these fish are released after capture.

High fishing pressure with minimum size limits can also apply selection pressure by favouring fish that mature at a smaller size, thus driving the population to 'dwarfism' (Conover and Munch 2002). The implications of this potential change on Murray Cod are unknown.

The maintenance of adequate breeding stock is essential for the continuation of 'wild stock' populations and such populations are at greater risk with lower adult numbers and potentially lower fecundities from younger adult fish. Many populations however, especially in impoundments, are managed as 'put and take' fisheries where not all stocked fish may be required or expected to become sexually mature. The objectives for such populations should be made explicit with different objectives set for conservation management actions.

The continuing legal use of set-lines for recreational take of Murray Cod in NSW and Qld is a contentious issue, polarising community opinion. The use of set-lines targets large fish that are unlikely to be effectively harvested by rod and line anglers, and the selective removal of large reproducing adults may have a substantial impact on population viability (Nicol *et al.* 2005). The document *Recreational Fishing in Australia: A National Policy (NRFWG 1994)* identified as one of 16 key principles for recreational fishing that "Preference should be given to recreational fishing methods in which the fisher is present…". Set-lines do not satisfy this principle. The use of set-lines and other regulations for recreational angling are currently being reviewed by NSW and SA fisheries authorities. In SA, the review includes documentation of the history of changes to size and bag limits, comparison of size and bag limits with those in other States, and a review of information on each species currently regulated (including key fishery biological characteristics, and effectiveness of bag limits in controlling recreational harvest).

There were few regulations for recreational fishing for Murray Cod prior to 1992, but all jurisdictions now have regulations governing cod fishing, including size and bag limits, and closed seasons (Lintermans 2005). It would be valuable to have a consistent regulatory regime between States and Territories to minimise confusion regarding regulations. The high release rate (77%) of Murray Cod caught by anglers suggests good compliance with the legal minimum size (Park *et al.* 2005), and there is a growing trend among some anglers to practice catch and release. While many anglers do observe the fishing regulations and release undersize fish, Murray Cod are quite sensitive to handling, and are very susceptible to fungal infections when handling removes skin mucous and scales. The impact of angling capture and release on the survival rate of released Murray Cod is not known, but studies on other recreational freshwater fish species indicate post-capture mortality rates between 1% and 70% of released fish (Muoneke and Childress 1994). The effects of catch and release on future breeding success of captured Murray Cod is also unknown. Fisheries Victoria is currently undertaking research into the impacts of catch and release.

Illegal Fishing

Poaching of Murray Cod and capture by illegal methods, including wire traps, set and cross lines, was considered to be a threat to some populations as long ago as the 1950s (Langtry, in Cadwallader 1977). Fisheries officers in South Australia and New South Wales report detecting hundreds of illegal traps each year (pers. comms., cited in Kearney and Kildea 2001). Illegal fishing methods, especially using drum nets, often target fish during the breeding season when they are more vulnerable, through increased activity associated with spawning such as pre-spawning movement, and large catches are taken in NSW through illegal fishing (Rowland 2005). The current illegal catch has not been quantified but is estimated to be very high, perhaps as high as or higher than the recreational fishery (Kearney and Kildea 2001, Lintermans and Phillips 2005). Take by illegal methods, especially wire traps, is indiscriminate and highly injurious to cod and other non-target species. Illegal, unreported and unregulated fishing is a significant threat to the sustainability of native freshwater fish resources including Murray Cod, and also disadvantages legitimate users and the wider community. Notwithstanding the ban on commercial fishing and perhaps because of it, the illicit market demand for wild caught cod remains strong.

Stocking and Translocations

Stocking and translocation of fish has been credited with the re-establishment of cod populations in several upper tributaries in northern NSW, after major declines and some local extinctions in the early 1900s (Rowland 2005). Principle concerns relating to stockings and translocations include the establishment of populations outside of their natural range, and the implications of release of hatchery produced fish, which have a limited genetic base, into natural systems (Phillips 2003).

Translocations

Murray Cod have been historically translocated into many areas, both within and outside their natural range, the latter translocations resulting in the establishment of several extra-limital, 'feral' populations (see Part B: Distribution), that may be a threat to the fish and large invertebrate fauna of these areas, especially in the Cooper Creek system (J. Pritchard DSE-ARI pers. comm.). In some recent cases, Murray Cod have been 'rescued' from lakes and rivers drying up and released into other waters, usually with little thought to any impact on fish populations in the receiving waters.

A National Policy for the Translocation of Live Organisms was produced in 1999 (MCFFA 1999) and all States and Territories are required to develop translocation guidelines for their jurisdiction that are consistent with this national policy. Victoria produced Guidelines for assessing translocations of live aquatic organisms in Victoria in 2003 (DPI 2003). NSW DPI is currently preparing a Fish Stocking Policy and Procedures Manual which will include Stocking Review Guidelines. Environment ACT has a fish stocking policy - *Fish Stocking Plan for the ACT 2001-2005* (Environment ACT 2000). PIRSA has a draft stock enhancement and translocation policy, and Queensland has a fish stocking and translocation policy outlined in *Overview of Fisheries (Freshwater) Management Plan 1999* (Queensland Fisheries Management Authority).

Stocking

Stocking programs are primarily undertaken for recreational angling opportunities, not conservation. Stocking is a management option often suggested to reinforce reduced fish populations, and has been adopted as a management tool by fisheries agencies and angler organisations. Stocking of Murray Cod fingerlings from hatcheries is currently an important management tool used to supplement or create cod fisheries across the Murray-Darling Basin, and can also aim to assist in long-term conservation of a population. An estimated 1,000,000 cod are stocked throughout the Basin each year, mostly in impoundments rather than rivers (Lintermans *et al*. 2005), although some stocking of weirs occurs. The majority of stockings have occurred in Victoria and New South Wales. The total number of Murray Cod stocked prior to 2004 by State is: Victoria 2.89 million, NSW 2.85 million, ACT 405,160 and Qld 320,000 (Lintermans *et al.* 2005). Fisheries Victoria stocks approximately 200,000 Murray cod fingerlings annually.

Stocking is often perceived as a 'panacea' to declining fish populations (Harris 2003), as it provides an easy management option that may result in deferring more difficult, expensive and controversial, but more effective management options. The effectiveness of Murray Cod stocking has not been quantified, and while it is probably most effective in impoundments, it is riverine populations that are under threat (Koehn 2005b). Stocking can provide some positive consequences such as the recolonisation of areas affected by threatening processes in the past, where those processes have ceased to be detrimental on fish populations and areas have been rehabilitated. There are also positive social and economic benefits associated with stocking Murray Cod. Fisheries Victoria is currently evaluating the benefits of stocked fish on populations.

Stocking is generally not a long-term conservation solution, as it may be 'masking' the true status of the species, and mask natural population recruitment levels. Its necessity highlights the fact that populations may not be sustainable under current exploitation rates or habitat conditions (Koehn 2005b; Lintermans *et al*. 2005). Stocking may also direct efforts away from more difficult but fundamental habitat improvement/threat amelioration activities that are necessary to achieve sustainable population levels without artificial enhancement.

Genetic Issues

A major problem with translocation and stocking occurs through loss of genetic integrity and fitness from wild populations, and shifts in genotype due to swamping of remnant populations with hatchery-bred fish, often from a much narrower genetic base. Hatchery-produced fish from a narrow genetic base may adversely impact genetic diversity of wild populations, especially if hatchery fish 'swamp' remnant wild populations. The genetic diversity of Murray Cod released from Victorian hatchery stockings in 2001/2 was found to be not representative of natural populations, with only 6 of 11 haplotypes present (Bearlin and Tikel 2003). Such genetic restriction may be more severe in non-government hatcheries, and would be further exacerbated by line-breeding for aquaculture for human consumption. There is currently no monitoring of genetic stocks of hatchery fish. Genetic research is underway to develop genetics models that will evaluate the impacts of various hatchery and stocking practices for Murray Cod (Brett Ingram, DPI, pers. comm.).

The development and implementation of quality assurance and accreditation schemes for hatcheries in each State and Territory would help ensure that stockings of hatchery produced fish into the wild will not adversely affect the genetic diversity of natural populations and prevent the introduction of unwanted biological material into the wild. A Hatchery Quality Assurance Program (Rowland and Tully 2004) has been developed for NSW. The collection of wild fish as broodstock is also an important issue that requires clear policy to ensure it is undertaken in a sustainable manner. The NSW Freshwater Fish Stocking Fishery Management Strategy (NSW DPI 2005) includes a Broodstock Collection and Management Policy.

Diseases

Very little is known about the prevalence and impact of diseases on Murray Cod. However, most naturally occurring pathogens are unlikely to be a problem except to injured fish, or where water quality deteriorates and fish become highly stressed. Fungal infections occur on fish subject to rough handling on capture, and may reduce survival of fish released after angling capture. The major concern probably relates to those exotic diseases introduced to Australia with imported fish, and have found their way into the environment. Diseases and pathogens of potential major concern include the Epizootic Haematopoietic Necrosis (EHN) virus, Viral Encephalopathy and Retinopathy (VER), Goldfish Ulcer Disease (GUD), Asian Fish Tapeworm *Bothriocephalus acheilognathis* and the parasitic copepod Anchorworm *Lernaea cyprinacea*. The introduced Redfin Perch carries EHN (Langdon *et al.* 1986), to which Murray Cod and other native species such as Silver Perch and Macquarie Perch are highly susceptible (Langdon 1989; Langdon *et al*. 1986; Langdon *et al.* 1987; MDBC 2004a). A MDBC project is currently underway investigating the susceptibility of native fish species to EHN and its epidemiology in the wild.

A new iridovirus has been detected in cultured Murray Cod in Victoria but has not yet been detected in wild fish (Prof. Richard Whittington, pers. comm.; unpubl. data). The abundance of some alien fish such as Carp and Eastern Gambusia may act as source for introduced pathogens such as Anchorworm and Asian Fish Tapeworm. Ectoparasitic protozoans including *Chilodonella* species, *Ichthyophthirius* species, *Myxosoma* species and *Trichodina* species are widespread and can be problematic in fish culture conditions (Ashburner 1978; Ashburner and Ehl 1973; Langdon 1989; Langdon *et al*. 1986; Langdon *et al.* 1987; Rowland and Ingram 1991), but their occurrence or impact in the wild is unknown. *Chilodonella* infestation has killed adult Trout Cod kept at a hatchery (Ingram and Rimmer 1992) and has been suggested as a threat to wild populations (Douglas *et al.* 1994). There is the potential to introduce disease to wild populations through the release of hatchery-bred fish. All hatcheries breeding Murray Cod need to comply with National Policy for the Translocation of Live Aquatic Organisms guidelines (MCFFA 1999), requiring disease screening prior to release.

Climate Change

The threat posed by climate change ('global warming') will potentially have significant and far-reaching impacts on the Murray-Darling River system. The consequences for much of south-eastern Australia (including the MDB) are predicted to be an overall reduction in rainfall, less winter/spring rainfall, possibly increased summer rainfall, more frequent and increased length of

dry periods, and an increase in the extent and frequency of extreme rainfall events. The potential increases in temperatures (both minimum and maximum) will also increase evaporation rates, so not only will less rainfall, with less runoff, but more surface water, especially from lakes and impoundments, will be lost to evaporation. All of this means less water in the rivers, especially at crucial times such as the spring-early summer breeding period for species such as Murray Cod, and over summer. Such conditions are likely to potentially increase pressure on many native fish including Murray Cod, through reduced flows and increasingly stressed rivers, with a much higher risk of fish kills during summer. During periods of drought where fish retreat to permanent water refugia, angling pressure may become focussed on these areas. Investigations of scenarios for freshwater fish from climate change and reductions in river discharge found that both could reduce freshwater biodiversity and have implications for survival of species (Xenopoulos *et al.* 2005).

Management Practices

There are many rehabilitation and research activities occurring across the range of Murray Cod, both within riparian and instream habitats. These include both broad scale, State and regionally based programs. There is great potential for Murray Cod to benefit from many of these programs both directly and indirectly. Many such programs are already occurring in catchments where Murray Cod occur, and the species will be a major beneficiary of the *Native Fish Strategy* and *The Living Murray* programs. Several environmental programs of significance to Murray Cod conservation are currently funded under these initiatives, including increased environmental flows in the Murray River and the Murray fishways program that is restoring fish passage from the sea to Lake Hume. While a range of management practices planned or underway may be of benefit, it needs to be recognised that there are also some management practices that may be detrimental to Murray Cod and jeopardise their recovery.

Management practices required for conservation of Murray Cod include:

- Improved flow regimes in the Murray-Darling River system, including provision for environmental flows during the breeding season.
- Habitat restoration programs, especially resnagging river reaches, and rehabilitation of riparian zones to ensure a continuing supply of snags, other organic material and shade.
- Provision of both upstream and downstream fish passage in the Murray-Darling River system through installation of fishways or removal of redundant weirs.
- Reduction in the length of rivers affected by cold water pollution.
- Management of low flows and water releases to reduce the incidence of fish kills.
- Management of practices to minimise loss of fish through irrigation.
- Actions that enhance the sustainability of current Murray Cod populations such as the ongoing management of recreational fishery take.
- Consideration of the establishment of protected areas for Murray Cod.

Management practices with the potential for detrimental impact on Murray Cod include:

- Removal or shifting (including realignment) of large snags, other structural woody habitat and other cover such as rocks from potential habitat, including floodplain channels. Where this is unavoidable (e.g. for protection of assets such as bridges), alternative suitable habitat should be created as a compensation or offset.
- Reduction in/alteration of flows, such as abstraction of more water from the system.
- Releases from impoundments of poor quality water that is detrimental to fish populations downstream.
- Removal of water from rivers (e.g. irrigation channels) without preventing loss of fish through these systems.
- Building barriers to migration/movement such as dams, weirs, causeways and levees.
- Removal or degradation of riparian vegetation/habitat.
- Events leading to increased siltation or sedimentation, such as works on riverbank and floodplain.

- Release of potential predators/competitors in areas where natural or stocked populations occur.
- Transfer of alien species (including native translocations) through inter-basin transfers.
- Pesticide and fertiliser run-off changing nutrient regimes leading to algal blooms, reduction in dissolved oxygen, increasing sedimentation rates etc.
- Legal and illegal take from key wild populations that alter population structure and threaten sustainability.

Social Issues and Impacts

Murray Cod is an icon species, and has significant economic, cultural, recreational and environmental value for Australians (Koehn 2005a; Rowland 2005; Sinclair 2005a, 2005b). Indeed, it has been described as the 'flagship freshwater fish for all of Australia' (Kearney and Kildea 2001). Murray Cod traditionally was a major part of the diet of aboriginal tribes living adjacent to inland waters, and an important cultural icon for these tribes (Lawrence 1971; Ramsay Smith 1930). Early European settlers also used Murray Cod as a food source, and the species was once common enough to support commercial fisheries throughout its range. As one of the largest freshwater fish in Australia, the Murray Cod generates considerable public interest because of its size and association with the Murray-Darling River system. It is a premier, highly sought after, freshwater angling species, with an estimated 566,000 anglers fishing in the MDB during 2000/01, with 22% targeting Murray Cod (Park *et al*. 2005). There are significant social and economic benefits of recreational fishing for cod to local communities. It is also important in aquaculture, as a food fish and for stocking for recreational angling. Murray Cod is a draw-card for tourism to the Murray-Darling Basin, and giant cod replicas can be found in several towns in the region including Swan Hill (Vic) and Tocumwal (NSW).

These qualities of Murray Cod transform its significance from being merely fish to being important components of Australian folklore and cultural heritage (Koehn 1994). The species also provides a significant way for the community to connect to the river environment, and the management of Murray Cod populations and their riverine habitats becomes the management of a part of Australian cultural heritage (Sinclair 2005a). As such, many Australians have a stake in the sustainable management of Murray Cod populations and their habitats. Many Australians hold passionate views about Murray Cod, be they angler, scientist, riverside resident, environmentalist or water manager. For instance, public reaction to a major fish kill in the Goulburn River (Vic) in 2004 led to the Victorian Government to establish an environmental audit of the whole river downstream of Lake Eildon, the first of its kind in Victoria (Sinclair 2005a). *The Environmental Audit of the Goulburn River – Lake Eildon to the Murray River* (EPA (2005) undertaken by independent auditor John Nolan, produced 60 recommendations, each of which identified agencies/authorities responsible for their implementation. In the government's response to the audit, it identified a range of new and existing initiatives to improve the health and management of the Goulburn River including the creation of the Environmental Water Reserve, monitoring of ecological responses to the reserve, investigation of fish passage, a research partnership, the completion of a Statewide Waterway Incident Protocol, the completion of the Goulburn-Broken Regional River Health Strategy and monitoring of Trout Cod populations. The strong reaction to fish kills and the perceived inadequate response to dealing with them, especially as to identifying the causes and implementing remedial action, demonstrate the feeling with which the community holds and views Murray Cod (Koehn 2005a; Sinclair 2005a). Recent fish kills (Koehn 2005a) indicate rivers are under stress but are being managed more for water supply than for ecosystem well-being and threatened species protection (Sinclair 2005a).

The Murray-Darling River system is already the focus of considerable management attention, through the Murray-Darling Basin Initiative, and subsidiary programs such as *The Living Murray* and *The Native Fish Strategy* (NFS) (for details see www.mdbc.gov.au). Major environmental initiatives such as plans to restore significant environmental flows to the Murray River and a shift to more natural flooding regimes will potentially benefit species like the Murray Cod. A program to provide fish passage over barriers such as weirs is in place in the Murray-Darling River system. Rehabilitation of riparian zones is being initiated and undertaken in many regions by management agencies and local communities. Community involvement in these programs is

facilitated through the MDBC Community Advisory Committee and the NFS Community Stakeholder Group. Stocking programs for both threatened and other native fish species are undertaken by State agencies and angling groups in rivers and impoundments which provide some benefits. One of the community expectations of these management actions is increased abundance of native fish species, including Murray Cod.

The principal potential impacts of this Recovery Plan relate to issues concerning recreational angling. The long-term decline in Murray Cod populations has deprived many rural communities of the social, recreational and economic benefits provided through recreational angling. The widespread rehabilitation of Murray Cod populations will provide many positive benefits, including increased tourism and cultural assets, to rural Murray-Darling Basin communities in these areas. There will be a continuation or potential enhancement of existing protection measures, including current regulations for size and bag/possession limits, seasonal closures of waters to fishing, provision of advice to anglers through signage and to recreational fishing guides, and patrols and inspections by fisheries officers to check compliance with regulations. These measures are unlikely to have any significant additional social impact above that already occurring in regions where Murray Cod occur. The impacts of any changes to angling regulations will incorporate socio-economic impacts and must be considered across the range of Murray Cod over the longer term.

The ideals of recreational anglers and conservation groups align well with management for the recovery of Murray Cod, through their involvement in habitat protection, rehabilitation, compliance and population monitoring. There is already a major shift in angler attitudes, with improving angler ethics and conservation sentiment towards the Murray Cod (Harris 2005). The Murray Cod is a highly prized species among recreational anglers, and surveys suggest a high level of compliance with fishing regulations, and a growing trend among some anglers to practice catch and release (Park *et al.* 2005). The National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003) estimated a release rate of 77.6% for Murray Cod. The days when anglers would proudly display the carcass of a very large Murray Cod hanging from the clothes line are fading. Now, many anglers display a photograph and are justifiably proud to proclaim that the fish was returned to the water alive and well. In the 21st Century, the killing of such a large, decades-old, creature is increasingly coming under public scrutiny and debate. The National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003) found that the primary motivation of 37% of fishers was 'to relax and unwind' and only 8% of fishers considered catching fish for food as their primary motivation.

While catch and release is becoming more commonly practiced by anglers, fish damage and mortalities associated with such releases remain unknown and should be determined so that any impacts on populations can be assessed. Additional education programs including proper fish handling techniques may help alleviate such impacts. Poaching is still a serious problem in some areas (Kearney and Kildea 2001), and regular compliance patrols are still required. Due to the methods used to illegally harvest fish, particularly for commercial gain, take is non-discriminatory at both species and size levels. Death rates associated with these measures can be quite high, resulting in wastage. Regulating take means that size of fish, number of fish and gear used can be managed to minimise impacts on populations; this needs to be strengthened with meaningful penalties to act as deterrents.

There is some anecdotal and limited fisheries data that indicates that in some northern areas of its range, Murray Cod may have increased over the last 5-10 years (Rowland 2005). There is evidence that some populations in NSW, which encompasses the bulk of the range of the Murray Cod, are showing signs of increase over the last decade (Rowland 2005). Surveys in NSW in the last decade indicate increasing numbers of cod throughout the State (Gilligan unpubl. in Rowland 2005), and anglers have reported improved fishing in recent years. A compilation of all recent NSW survey data by Gilligan (NSW DPI 2007 unpubl.) indicates that Murray Cod populations in the Border Rivers (excluding the Severn below Pindari Dam), Gwydir, Namoi, mid-Murrumbidgee, lower Darling and lower Murray rivers appear to be in good condition (defined as widespread, abundant and recruiting). Populations in other areas such as the Lachlan, Macquarie, mid-Darling, Barwon, upper Murray rivers and the Severn River below Pindari Dam, although showing reasonable abundance of adult Murray Cod appear to have had poor recruitment in recent years.

There is also some anecdotal evidence of a limited recovery in southern parts of its range (Rob Loats, VRFish, pers. comm.). Victorian anglers have consistently reported a resurgence of

catches of Murray Cod in most year classes in the Murray River and its tributaries (Murrumbidgee, Wakool, Edwards, Neimur, Lindsay-Mullaroo and other Victorian riverine systems with many reporting the best Murray Cod fishing in decades (Rob Loats, VRFish, 2006). However, there appears to be little evidence for the recovery of Murray Cod populations in Victoria based on data from a range of surveys. There are considerable concerns over the loss of Murray Cod from the Mitta Mitta River (Koehn *et al.* 1995), the lower Broken Creek (Koehn 2005a) and fish kills in the Goulburn and Ovens Rivers (Koehn 2005a). While some recovery of fish populations has been recorded in the lower Broken Creek due to the installation of fishways (J. O'Connor, DSE unpubl. data and Rob Loats, VRFish pers. comm.), in 2005/06, numbers of Murray Cod in the lower reaches had not recovered to pre-fish kill levels. (J. O'Connor, ARI unpubl. data). Occasional angler captures of cod have been reported from the Mitta Mitta River but it is not known if these are resident fish or migrants from Lake Hume moving into the river during years of lowered irrigation releases. SRA audit surveys of the Ovens River conducted by electrofishing do not appear to show changes to population numbers (J. Lieschke, ARI unpubl. data). Comparison of two different surveys of the lower Goulburn River has indicated an apparent increase in Murray Cod numbers between 1982/1983 and 2003/04 (Koster *et al*. 2004). A continuation of the 2003/04 surveys have indicated spawning and recruitment in each year but a decrease in the abundance of legal sized Murray Cod in the 2004-2006 period (Koster *et al.* unpubl. data). Recent fish surveys in the lower Loddon and Campaspe rivers (SKM 2007) and Gunbower Creek (John Douglas, DPI, pers. comm., Richardson *et al*. 2005) have indicated only low numbers of Murray Cod. Comparisons of two different surveys of the lower Goulburn River have indicated an apparent increase in Murray Cod numbers between 1982/83 and 2003/04 (Koster *et al*. 2004). A continuation of the 2003/04 surveys has indicated spawning and recruitment in each year but a decrease in the abundance of legal sized Murray Cod in the 2004-06 period (Koster *et al*. unpubl. data). A single predominant cohort of Murray Cod was collected in the first two years of the study and these fish were approaching the legal size limit in spring 2005, However the cohort largely disappeared from the population between spring 2005 and autumn 2006. Angling pressure and/or changes to the summer flow regime are possible reasons for the decline (Koster *et al.* 2006). This pattern has continued for the 2006-07 sampling period (Koster, DSE-ARI, pers. comm.).

There have been reports of improved angler catches of Murray cod in downstream reaches in SA including Chowilla (Peter Teakle, pers. comm.) although there is some variance in opinion, between angling groups' observations and government departmental survey data, regarding status of Murray Cod in South Australia. Prior to 2003, data on the stock status of Murray Cod in SA reaches of the Murray River were derived from commercial fisheries data. This fishery was discontinued in 2003 and since this time, data has been collected using fishery independent methods. Length-frequency data from commercial fishers pre 2003 indicate that strong recruitment of Murray Cod in the SA reaches of the Murray River last occurred in 1994 (Ye and Zampatti 2007). The data also indicate that a low level of recruitment may have occurred in 1998 and 2000. Recruitment in these years was associated with instream and overbank discharges in the river of approximately 30,000 to 100,000 ML/d. Fishery independent data collected from 2005 onwards indicate that minimal Murray Cod recruitment has occurred since 2000 with the majority of fish (collected by electrofishing, drum netting and gill netting) being greater than 700 mm in length. Nevertheless, current research in flowing anabranch habitats indicates that these regions may provide a base level of Murray Cod recruitment during years of sustained low or uniform (entitlement) flows in the South Australian reach of the Murray River.

Quantification of any increases in Murray cod populations is needed so that they can be placed in the context of the overall declines that have occurred in the past. Reasons for any population increases need to be determined and if populations are improving from their historically low levels, this should be viewed as a positive step towards overall rehabilitation. However, until the species' status has improved to the extent that it is no longer considered threatened, active management is required to protect and rehabilitate the species.

There is some public perception that Murray Cod populations have "recovered" or are "secure" in some areas and don't need further protection. This perception may have come about through the loss of inter-generational memory of past abundances, the broad distribution of the species, a lack of knowledge of declines and local extinctions in other areas or dismissing local losses as not serious because of abundance elsewhere. High stocking rates at some sites can also provide impressions of good populations, although can mask natural population recruitment

levels. Increasing angler efficiency at catching cod through better fishing gear, use of boats and depth sounders also make it easier to catch cod (Lintermans *et al*. 2005). Managing public perceptions and expectations will be a major issue in implementing this Recovery Plan. The observations of recreational anglers are an important contribution to assessing the species' status, and should be combined with comprehensive and quantitative surveys to clarify current abundance across the species' range.

Changes to management practices that may alleviate cold water pollution and hence any existing cold water fisheries, or introduction of additional protection measures for Murray Cod, will need to be subjected to public consultation including with angling, aquaculture and tourism industry groups. Threatened species recovery must be considered within a social context; in the past this has generally been externalised from plans and left to a separate socio-political process (Brown *et al.* 2003).

Some actions will have a short-term social cost. However, this needs to be balanced with the long-term goal of achieving sustainable populations, so that current access opportunities enjoyed by recreational anglers now can be maintained for future generations. Murray Cod are now bred in hatcheries and stocked in many locations for recreational angling, so that angling opportunities for the species have increased in some areas particularly impoundments and some weirs over the last couple of decades.

In gathering information for this Recovery Plan, it became clear that two issues in particular evoked polarised strong and passionate views: (1) Using set-lines to catch Murray Cod; and (2) Establishing protected areas for (or protected populations of) Murray Cod.

The use of set-lines

The use of set-lines is still permitted in New South Wales and Queensland. The issue of set-lines to catch Murray Cod is seen by some groups as an archaic anachronism that has nothing to do with the sport of recreational angling. However, other groups justify the continued use of set-lines as a long-used method of harvesting cod for food. The document *Recreational Fishing in Australia: A National Policy (NRFWG 1994)* identified, as one of 16 key principles for recreational fishing, that "Preference should be given to recreational fishing methods in which the fisher is present...". Set-lines do not satisfy this principle. Fishing regulations are reviewed on a regular basis by government agencies, which provides the ability to review the use of set-lines.

Protected areas

Establishing protected areas for Murray Cod has also been suggested as a management option worthy of consideration. Several highly threatened species (listed under the EPBC Act as Endangered) such as the Trout Cod, Eastern Freshwater Cod and Macquarie Perch already have partial or complete protection. In its recommendation to the Australian Government on the nomination of Murray Cod for Listing under the EPBC Act (as Vulnerable), the Threatened Species Scientific Committee noted that there were no protected areas or protected populations of Murray Cod (TSSC 2001).

The potential use of protected areas for Murray Cod has been opposed in principle by some agencies and angler organisations, but supported by other agencies and conservation and community groups. The Australian Conservation Foundation (ACF) and World Wide Fund (WWF) have developed detailed policy documents on the potential for protected areas in Australia, and strongly support the concept. The Murray Cod Recovery Team has also been approached by a local management agency to recognise the Mullaroo Creek/Lindsay Island region as a priority management area in Victoria. There is a need for consultation regarding the concept of protected areas and it should be seen as only one of many management measures. Whether establishment of protected areas for Murray Cod is a suitable measure to use as one of a suite of actions to improve the species' conservation status is yet to be evaluated.

The MDBC recently commissioned a report to explore the concept of establishing a system of Habitat Management Areas (HMAs) across the Basin (Phillips and Butcher 2005), as advocated within the NFS, and this should be used as a framework for the consideration of any such areas for Murray Cod. This report examined international and national experiences, the science required to underpin the establishment of HMAs, the management prescriptions and approaches needed, and the policy and administrative practicalities of implementation across the Basin (Phillips and Butcher 2005). A National Reserve System (NRS) approach is also being considered to achieve a system of terrestrial protected areas (NRMMC 2005), and there

is the possibility that amendments may be made in the future to ensure freshwater ecosystems are incorporated into this NRS approach.

The time to act

Given the recognition that Murray Cod is now listed as "Vulnerable" nationally under the EPBC Act 1999, there is a need to implement conservation actions now to improve its status, rather than risk the possibility of further decline. If management actions are not implemented now, consequences of awaiting further decline will include a reduced likelihood of the species' recovery as well as a reduced likelihood of successful investment of money spent on the species' rehabilitation. Principles of a Recovery Plan should include improving the conservation status of a threatened species and preventing further decline i.e. in this case, the eventual removal of the species from the EPBC Act and preventing it from entering the Endangered status.

Many threatening processes still operate across the species' range and require active management to address their impact on Murray Cod as well as many other freshwater fish species and their habitats. Management strategies have already been initiated specifically to address the species' decline e.g. reviews of angling regulations in NSW and SA. A change in management approach is now required, from a species once harvested by commercial (in the near past) and primarily managed for recreational anglers, to one that receives additional conservation and recovery management. This is especially so in Victoria where the species is recognised as endangered. Reduced Murray Cod populations are more vulnerable to threats due to low population numbers.

The Precautionary Principle is a well recognised concept that has been endorsed internationally e.g. at the Earth Summit in Rio in 1992, and has been defined in international instruments such as the Food and Agriculture Organisation Code of Conduct for Responsible Fisheries, and the Agreement for the Implementation of the Provisions of the united Nations Convention on the Law of the Sea. These share the following common wording and ideas of the principle *…"States should apply the precautionary approach widely to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment. The absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures."* The Precautionary Principle should now be applied to management decisions for Murray Cod. Most populations now occur in managed rivers where recovery from catastrophic events may be more difficult than in the past due to the lower populations, fragmentation of suitable habitat and the presence of other threats.

Economic Issues and Impacts

Murray Cod is economically important through its contribution to tourism and social outcomes and its true contribution to society could greatly exceed current perceptions (Kearney *et al.* 1999). Murray Cod, along with other larger Murray-Darling fish species, once supported commercial wild fisheries in South Australia, Victoria and New South Wales. Commercial fishing of wild Murray Cod in the MDB ceased in NSW in 2001, Victoria in 2002 and South Australia in 2003. The aquaculture industry for Murray Cod however in New South Wales and Victoria is rapidly expanding, with over 150 tonnes per year now produced for domestic and international markets (Ingram *et al*. 2005). In South Australia, Murray Cod is a permitted by-product species in the Lakes and Coorong Fishery, although there have been very low catches (<300 kg) in the last five years.

Murray Cod is a premier, keenly sought after species by recreational anglers, but there are no quantitative assessments of its recreational value. However, the recent National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003) has provided valuable information on harvest. This survey identified an annual harvest of Murray Cod of 108, 352 fish, of which over 90% were from rivers. The majority of fish were estimated to have been taken from NSW (93,973 fish, 87%) followed by Victoria (11,943 fish), South Australia (2278 fish) and Queensland (158 fish). The survey estimated a total catch of 483,284 fish, with a release rate of 77.6%. The estimated annual harvest by weight was 144,222 kg (93,973 kg NSW, 27,469 kg Vic and 22,780 kg SA). It had previously been estimated that 140,000 fish weighing 220,000kg was captured in New South Wales alone in 2000 (Henry unpubl. in Kearney and Kildea 2001), leading these authors to describe the economic significance of Murray Cod as 'enormous'. Angling for Murray Cod provides a major economic benefit to many areas within the MDB.

The implementation of this Recovery Plan is unlikely to cause significant additional adverse economic impacts, particularly as all commercial fisheries for Murray Cod have already been closed. In relation to recreational fishing, improvement in the status of the species would lead to improvements in recreational fishing catch and increase economic benefits to regional areas. If management actions to improve the species' status are not put in place there is the potential for these economic opportunities to be lost. The social and economic benefits/consequences of intended actions in this recovery plan will be considered as part of any implementation process. It will be valuable for management agencies to form important partnerships with the recreational angling community, since this sector has useful information to assist in the future sustainable management of Murray Cod.

Implementation Information

Strategy for Recovery

The Native Fish Strategy for the Murray-Darling Basin 2003-2013 (MDBC 2004a) has the vision of sustainable, viable fish populations and communities throughout its rivers. The overall goal of this Strategy is to rehabilitate native fish communities in the MDB back to 60% or better of their estimated pre-European-settlement levels after 50 years of implementation, through a range of management actions. The health of populations and communities of native fish species in the Murray-Darling River system is an indicator of the overall health of its rivers (Harris 1995). With recognition of the extensive decline of native fish populations, there is now an established need for active rehabilitation, rather than just managing to maintain current stocks (MDBC 2004a).

The workshop on Management of Murray Cod in the MDB formulated a vision for the future of Murray Cod across the Basin (Lintermans and Phillips 2005):

'Self-sustaining Murray Cod populations managed for conservation, fishing and culture'

The need for additional knowledge to improve the management of native fish species, including Murray Cod, is well recognised (Anderson 1988; MDBC 2004a). Such knowledge is necessary to provide a defensible scientific basis on which to undertake environmental restoration and species' conservation management. Filling knowledge gaps however should not prevent management actions being undertaken now to mitigate known threats to Murray Cod populations.

The Murray Cod faces landscape-scale threats across its range, including many of the issues that are impacting native fish populations in general in the Murray-Darling River system (MDBC 2004a). Addressing general threats to native fish populations will greatly assist the Murray Cod. The species is highly likely to benefit from integrated catchment management initiatives, including maintaining or restoring environmental flows, provision of fish passage past barriers, provision of in-stream fish habitat, and protection and revegetation of riparian zones to increase streamside cover and reduce erosion and sediment input into waterways. Many such programs are already occurring in catchments where Murray Cod occur, and the species will be a major beneficiary of the *Native Fish Strategy* and *The Living Murray* programs. Several environmental programs of significance to Murray Cod conservation are currently funded under these initiatives, including the Murray fishways program, that is restoring fish passage from the sea to Lake Hume, research on the impact of sustained high summer flows on habitat values, the contribution of stocked versus wild fish to fish populations, loss of fish to irrigation and pumping, and identification of important Murray Cod habitats. Monitoring the ecological response of the Murray Cod to these measures will be a key factor in managing the recovery of this species.

The strategy for recovery of Murray Cod will be to investigate its status, key biological and ecological attributes such as current distribution and population structure, spawning cues, movement, habitat and flow requirements. These requirements will need to be integrated into natural resource management programs in the Murray-Darling Basin, and the response of cod

populations to changing management conditions needs to be monitored. It represents the beginning of a systematic approach that involves the community. An important issue to address is building community support for conservation efforts, through education and awareness. Recovery actions need to be population-based rather than species based, to effectively engage the community (Lintermans *et al.* 2005). Managing community perceptions and expectations will be a major challenge. A key challenge will be defining responsibilities and integrating actions, especially as current efforts are hampered by multiple jurisdictions and unclear responsibility (Koehn 2005a). Expected outcomes after the first five years of implementation will be an improved understanding of distribution, population structure, threats, identification of priority actions, commencement of key actions for recovery, and improved understanding of Murray Cod conservation within the community.

The recovery program will add value to and complement river restoration programs throughout the Murray-Darling Basin, such as river health strategies by Catchment Management Authorities, *The Living Murray* and the *Native Fish Strategy*. While these and other programs target broad habitat restoration, the recovery program for Murray Cod will target actions specific to the species, and will provide an important monitoring component for determining the impact of restoration programs on cod populations. Long-term monitoring will be important for assessing the adequacy of current and proposed changes to water management arrangements in the Basin.

Setting a Target

The overall goal of this Recovery Plan is to rehabilitate Murray Cod populations in the MDB to 60% (or better) of their estimated pre-European settlement levels after 50 years of implementation. This 'aspirational' target is in line with the *Native Fish Strategy* target and will be achieved through a range of management actions. An intermediate target for Murray Cod will be to have it delisted as a threatened species under the federal EPBC Act with secure, sustainable populations that meet the recovery objectives.

There will be two distinct phases in the implementation of the recovery plan. The first phase will focus on data gathering where key populations and areas are identified and monitored. Understanding the population structure, status, dynamics and recruitment drivers of Murray Cod populations (Action 1.1) will provide an important baseline from which to be able to monitor improvements in the species' status and assess the effectiveness of the implementation of rehabilitation actions. Where particular key populations are declining, arresting this decline will be a key aim.

The second phase will be to set a target and a timeframe for delisting of Murray Cod under the EPBC Act. Interim targets will be developed for each Spatial Management Unit by the end of the first five years of this plan (Action 7.2).

Expected outcomes after the first five years of implementation will be an improved understanding of distribution, population structure, threats, identification of priority actions, commencement of key actions for recovery, and improved understanding of Murray Cod conservation within the community.

This Recovery Plan should be seen as the first five year plan, which will be reviewed and revised at the end of this timeframe. The Murray Cod is a long-lived, slow-growing species, and recovery will take many years to achieve. It is likely to take between 10 and 50 years of active management before a significant difference is made to the long-term recovery of Murray Cod. This corresponds to the 50 year timeframe within the *Native Fish Strategy*.

Focus of Attention of Management Actions

Murray Cod has a wide distribution and faces landscape-scale threats which vary in their character and intensity across its range. Thus appropriate management actions are wide ranging, complex and involve a range of agencies and jurisdictions. Recovery actions address the need for habitat management and rehabilitation and restoring ecological functioning. To achieve such goals it is important to identify specific and distinct areas which should be the principle focus for management.

The draft *National Recovery Plan for Murray Cod* incorporates the concept of using 'Spatial Management Units' (see Figure 1), Important Populations and Populations under Threat to facilitate implementation of recovery actions in particularly high priority areas. While every population is under a degree of threat, the significance of threats fall unevenly across the landscape. There are a number of locations that can be defined where populations are under a very high degree of threat, and require specific management attention. Similarly there are certain populations that may be significant according to genetic, ecological and management issues. The Murray Cod Taskforce and the Murray Cod Recovery Team developed a set of criteria to identify Important Populations and Populations under Threat across the range of this species. These are outlined in the associated document: the draft *National Recovery Plan for Murray Cod*. In some situations there may be overlap between areas recognised as Important Populations and Populations Under Threat. It is also possible that one population may include several Spatial Management Units.

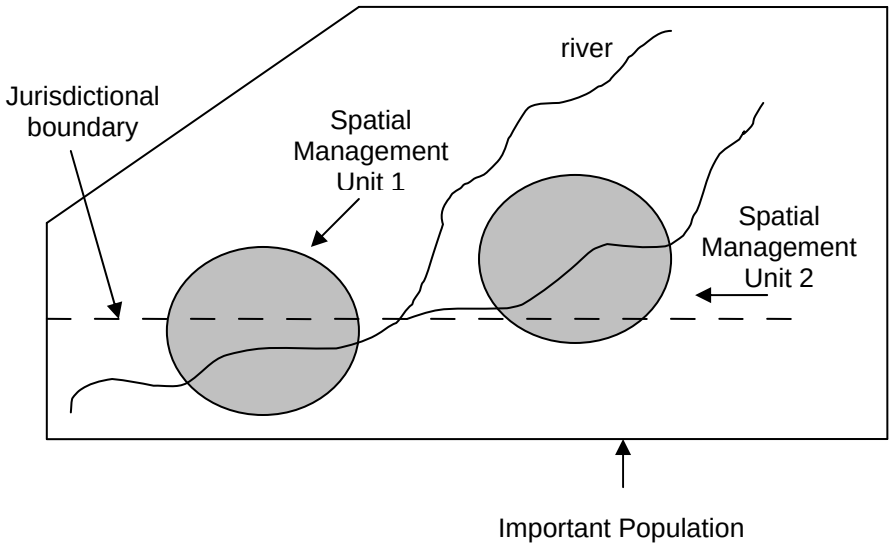

Figure 2. Jurisdictional boundaries, Important Populations and Spatial Management Units

Program Implementation and Evaluation

The Recovery Plan will run for five years from the time of implementation. The national Murray Cod Taskforce (MCT), established under the Murray-Darling Basin Commission's Native Fish Strategy Implementation Working Group (NFSIWG), will provide oversight and coordinate implementation of the Recovery Plan. The MCT was established to provide regular advice through the NFSIWG to the Ministerial Council, the MDBC Community Advisory Committee and the Native Fish Strategy Community Stakeholder Taskforce, on key management issues affecting Murray Cod. Local implementation arrangements, such as expert/technical working groups, will be formed where required, to facilitate implementation at the regional level, and provide advice to the MCT. Any technical, scientific, habitat management or education issue requiring skills not available within the Recovery Team will be referred to specialist organisations and individuals as appropriate. Implementation of individual actions will remain the responsibility of the relevant agencies and organisations identified in the Recovery Plan (subject to available resources), who will be responsible for preparing work plans and monitoring progress toward recovery within their own jurisdiction. The MCT will play a role in seeking funding for some actions, identify priority areas for implementation of particular actions, and facilitate liaison between agencies where required.

Proposed actions cover a range of methodologies including habitat management, research, survey, monitoring, information and education. Implementation will involve a range of partners

in recovery, including State NRM agencies and authorities, research institutions, and community groups including Aboriginal, angling and environment groups. Actions will be undertaken throughout the Murray-Darling River system, in Queensland, New South Wales, ACT, Victoria and South Australia, and at research centres including: the Arthur Rylah Institute for Environmental Research (Melbourne Vic), Narrandera Fisheries Centre (NSW), Murray-Darling Freshwater Research Centre (Mildura) and the South Australian Research and Development Institute (Adelaide SA) and Wildlife Research and Monitoring Unit (Canberra, ACT). Numerous agencies, including regional, State and Federal organisations, are involved in onground management of aquatic and riparian environments across the species' range. Thus they have both direct and indirect involvement of management of Murray Cod and its habitat. It is essential that actions within the Plan link in well and complement relevant onground river and riparian management plans. This will maximise the opportunities for obtaining funding as well as maximise the relevance and benefits of actions to Murray Cod and the wider riparian and aquatic environment. MCT will provide some coordination.

The recovery plan includes a large number of actions across a wide area, and involves many agencies. A number of actions under Objective 7 (Manage Recovery Plan Implementation) address the need to coordinate the implementation of these actions, their integration with other programs, and liaison and communication with relevant agencies. The employment of a Murray Cod Recovery Plan Coordinator may be beneficial to maximise the implementation of the overall recovery plan to meet its objectives (Action 7.1).

Program Monitoring and Evaluation

Review and evaluation of progress towards recovery objectives is an important part of adaptive management for threatened species conservation. Individual organisations and agencies will be responsible for their own regular, informal evaluations of their projects. The Murray Cod Taskforce will be responsible for annual informal evaluation of project progress in implementation of the Recovery Plan. This process would be greatly assisted by the employment of a Murray Cod Recovery Plan national coordinator who could provide support to the Recovery Team and the Murray Cod Taskforce (Action 7.1). In addition, Action 7.8 also addresses the need to establish a monitoring program that provides updated population data to assess Murray Cod recovery and support Murray Cod management. The national coordinator could play a key role in this process. The development of such a monitoring program could facilitate the use of consistent methods and analysis, and identify a process by which the results of the numerous actions identified within the Recovery Plan could be collated and disseminated most effectively.

A formal, comprehensive review and evaluation of the recovery program needs to occur at the end of the five years of implementation, to determine how effective recovery has been, and to set the process and framework for next phase of recovery. Towards the termination of this Recovery Plan, an external reviewer will be appointed to undertake a formal review and evaluation.

Adaptive Management

An adaptive management approach should be considered so that management priorities and actions can be altered in light of results and new information. Many actions can also be undertaken and monitored within an experimental framework to enhance our knowledge.

Recovery Objectives

The Long-term Objective of recovery is to have self-sustaining Murray Cod populations managed for conservation, fishing and culture.

Within the 5-year life span of this Recovery Plan, the **Specific Objectives** of recovery are to:

1. Determine distribution, structure and dynamics of Murray Cod populations across the MDB.
2. Manage river flows to enhance recruitment to Murray Cod populations.
3. Evaluate the risks of threats and benefits of recovery options for each management unit.
4. Determine the habitat requirements of Murray Cod life stages and populations.
5. Manage the recreational fishery for Murray Cod in a sustainable manner while recognising the social, economic and recreational value of the fishery.
6. Encourage community ownership for Murray Cod conservation.
7. Manage Recovery Plan implementation.

The specific objectives and actions below align well with the priority objectives identified during the recent workshop Management of Murray Cod in the MDB (MDBC 2005) (Appendix 1).

Recovery Actions

Actions are listed below for each Objective. After each Action, a summary of task assessment is provided which indicates priority, timeframe, ease of achievement and responsible authorities. High priority actions are also denoted in bold type. The primary document *National Recovery Plan for Murray Cod* provides further indication of actions that should be the primary focus of attention in the first five years of implementation of the recovery plan.

The list of suggested responsible authorities is indicative only and needs to be determined within each jurisdiction. These actions have been thoroughly developed and reviewed at a workshop of the recovery team and the MCT over a period of two days. This approach follows the format outlined within *The Native Fish Strategy*, and the meaning of each term is explained in the legend below. Table 1 summarises the priority, feasibility, timeframe, estimated costs and agencies/organizations which may be involved in implementation and/or reporting on implementation of recovery actions. A summary of all objectives, performance criteria and actions is provided in Appendices 4 (a-c). All recovery actions are summarised in order of priority (Appendix 4a), ease of implementation (Appendix 4b) and timeframe (Appendix 4c).

Legend

Priority	Timeframe	Ease
Low	Short-term (<1 year)	Easy
Medium	Medium-term (1-5 years)	Moderate
High	Long-term (5+ years)	Hard

Agencies and organisations which may participate in implementation of actions and/or reporting on process of action implementation	
CWLTH	Commonwealth government agencies (e.g. DEWHA, DAFF, LWA)
LGA	Local government authorities
MCT	Murray Cod Taskforce
MDBC	Murray-Darling Basin Commission
MCRPC	Murray Cod Recovery Plan Coordinator
R&D	Cooperative research centres, CSIRO, Uni, research institutions
SCA	State conservation management agencies
SCMO	State catchment management organisation
SEPA	State environment protection authorities
SFA	State fisheries management agencies
SLMA	State land management agencies
SWMA	State water management agencies

Objective 1. Determine the distribution, structure and dynamics of Murray Cod populations across the MDB.

Justification:
This Objective supports the *Native Fish Strategy* Objective **1**: To repair and protect key components of aquatic and riparian habitats important for sustaining native fish populations.

Recovery Criterion:

An improved understanding of distribution, abundance and population structure of Murray Cod across the Murray-Darling Basin and incorporation of this information into NRM strategies and plans in the Basin.

Action 1.1 Review and synthesize published information on the population structure, status and dynamics of Murray Cod populations across the Basin.

Whilst considerable progress has been made in recent years to survey the inland rivers within the MDB there is a need to collate and synthesise this information for Murray Cod. In particular, the size structure, age structure, abundance, distribution, reproduction, movement and fragmentation of Murray Cod populations require documentation. Available sources of information include agency databases, individual project data, SRA, angler records and angler surveys. This will build upon the information in Kearney and Kildea (2001). This synthesis will allow a thorough gap analysis to proceed.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Short-term	MDBC, SFA, SCA, R&D, SCMO

Action 1.2 Identify gaps in distribution and population data and develop and implement a survey program to obtain data to address this.

This action follows Action 1.1. A thorough gap analysis will identify where deficiencies in data and knowledge on the size structure, age structure, abundance, distribution, reproduction, movement and fragmentation of Murray Cod populations. An important task in this action will be the development and implementation of surveys (scientific, angler and community) to address these critical knowledge gaps. Of particular importance is data relating to age/size/reproductive relationships. This will then be done at the management scale (see 1.5, 1.6 and 1.7).

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Long-term immediate start	MDBC, SCA, SCMO

Action 1.3 Determine the genetic composition of Murray Cod populations throughout the Basin.

Understanding the genetic composition of Murray Cod populations throughout the MDB is fundamental to minimising the risks from hatchery stocking, translocation and the aquaculture escapement. This will also allow compliance with hatchery quality assurance in relation to genetic composition of brood stock. Study of the genetic diversity of hatchery fish released in Victoria found only about half the haplotypes of natural populations were present. PIRVic is currently determining the natural genetic structure and diversity of wild populations of Murray Cod and assessing the genetic diversity of current hatchery stocks. Genetic research also has the capacity to rapidly improve our understanding of population dynamics for this species. Whilst this is a developing area of scientific investigation, opportunities to explore this technique should be undertaken.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Medium-term	MDBC, SFA, SCA

Action 1.4 Identify appropriate Spatial Management Units for Murray Cod management (jurisdictional, habitat zones, genetic Evolutionary Significant Management Units) across their range.

Currently the management of Murray Cod is delineated by jurisdictional boundaries with no consideration to the spatial and temporal scales that Murray Cod populations operate within. This may include a combination of jurisdictional, habitat zones or genetic Evolutionary Significant Management Units. Consequently, the ecological requirements, habitat and management requirements of populations may be compromised by existing boundaries. This action will identify the appropriate spatial and temporal scales and mechanisms for cross jurisdictional management.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Moderate	Short-term	MDBC, SFA, SCA, SLMA, SWMA, SCMO

Action 1.5 Prioritise the Spatial Management Units that require urgent or specific management actions: monitor and maintain these units.

Once Spatial Management Units have been identified (Action 1.4) there will be a need to identify those which should be the initial focus of management attention. The incorporation of a monitoring component within any active management programs within a Spatial Management Unit will enable an assessment of the effectiveness of actions.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Long-term	MDBC, SFA, SCA, SLMA, SWMA, SCMO

Action 1.6 Identify, protect and repair key aquatic and riparian habitats for Murray Cod in each Spatial Management Unit.

This action corresponds directly with a key objective within the *Native Fish Strategy for the MDB* (MDBC 2004), and was also identified (Objective 1) at the recent workshop for management of Murray Cod (Lintermans and Phillips 2005). This is a fundamental component in the recovery of this threatened species and links closely with many associated actions, particularly Action 1.4, 3.2, Action 4.1, Action 4.2 and Action 4.5 which relate to identifying and protecting significant areas.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Long-term	MDBC, SCA, SFA, SLMA, SWMA, SCMO

Action 1.7 Determine the structure (age, size, spatial connectivity), dynamics, movement, dispersal and migration levels of Murray cod populations in and between each Spatial Management Unit.

Utilising the information determined in Actions 1.1 to 1.4, identify and fill critical knowledge gaps in relation to structure (age, size, spatial connectivity), dynamics, movement, dispersal and

migration that effect each Spatial Management Unit. Data can be collected using angler returns, scientific research and other fisheries independent methods. Where feasible the collection of additional information should be coordinated in such a way that maximises learning for all management units (such as Active Adaptive/Experimental Management).

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Moderate	Long-term	SCA, R&D

Action 1.8 Investigate the role and relationships of Murray Cod within the fish community.

There has been concern raised in some areas of the potential impact of increased Murray Cod populations on populations of other species.

Task assessment

Priority	Feasibility	Timeframe	Agency
Low	Hard	Long-term	SCA, R&D

Action 1.9 Investigate the current reproductive status, age/size fecundity relationships, age at first reproduction, recruitment levels and longevity of key populations of Murray Cod.

Some quantitative evidence suggests Murray Cod exhibit variable growth with age, both within and between locations, although whether these differences are due to environmental factors, or underlying genetic influences is unknown. Current regulations attempt to ensure that each individual can reproduce before capture, although some fish above the legal length may be only three years old, and hence can be legally taken before reproducing. What proportion of the population fit into this category and whether or not these individuals are sexually mature is unknown. There is uncertainty around the age, size, and sexual maturity relationship (Kearney and Kildea 2001). If an adequate number of individuals cannot reproductively contribute to the population, the long-term capacity to support a recreational take may be limited and thus become increasingly reliant upon artificial breeding and stocking programs. Age/size/reproductive relationships need to be determined for key populations to provide an evidence base for managing populations and setting fishing regulations. This should include a determination of the importance of large, breeding individuals to overall recruitment levels of the population.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Long-term Immediate start	SCA, R&D

Action 1.10 Model the significance of larger size classes to recruitment and sustainability of Murray Cod populations, and develop management strategies to achieve sustainability where skewed population structure is unsustainable.

The importance of large reproductive adults to cod populations is unknown but assumed to be significant. Low numbers of fish in larger size classes have consequences for the viability of cod populations, with limited numbers of breeding fish contributing to annual recruitment. Modelling will clarify specific impacts to populations of varying abundances of larger size classes. Strategies to achieve sustainability where this situation occurs could include adjusting minimum length for take or further limiting the number of large fish that can be taken. This information may also be used to determine the impact of various capture methods. Data could be collected from angler takes or fish kills. Information obtained from Action 1.9 will be relevant to this action.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Medium-term	SCA, SFA

Action 1.11 Identify key recruitment areas in each Spatial Management Unit.

There are two important components of recruitment; the first being successful spawning and the second being the survival of these recruits to adulthood and subsequent reproduction. The action will determine whether there are important area and/or habitat for spawning and the ecological mechanisms that influence recruitment through each life-stage to adulthood. This may include nursery area for larvae, juvenile and adult habitats. This will be assisted by results from Objective 4.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Moderate	Medium-term	SCA, R&D

Action 1.12 Identify and quantify the environmental parameters that drive recruitment and population growth, especially age-specific survivorships.

The age-specific survival rates are influenced by both environmental and human factors (such as recreational angler take). The rehabilitation and long-term viability of Murray Cod populations requires that the population growth rate (a summary of the age-specific survival rates) of the species remains positive. Currently, there is no information on age-specific survival rates and this has been recognised as a key knowledge gap in the modelling and forecasting of population viability.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Hard	Long-term	MDBC, SCA, R&D

Action 1.13 Develop appropriate decision support tools and models that allow the future management actions for Murray Cod to be evaluated within a risk management framework.

The future actions that can be implemented to restore and manage Murray Cod are numerous. Presently, there are few tools available to examine and compare the benefits that are likely to arise from such actions. Suitable decision support tools and models include both science based population models and socio-economic models. Outputs from these models will be used to assist with setting future recovery objectives. There is a need to ensure models are updated with new information.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy Data dependent	Short-term ongoing	MDBC, SCA

Action 1.14 Develop and implement an integrated, long-term monitoring program for assessing recovery of Murray Cod populations in each Spatial Management Unit.

There is a need for long-term monitoring to assess efficacy of this recovery plan. Once populations, locations and methods for long-term monitoring are identified, ongoing monitoring needs to be undertaken to obtain data to gain an understanding of population distribution and changes. Data can be collected using angler returns, scientific research and other fisheries

independent methods. The results will be used to gain an indication of the impact of environmental management programs on Murray Cod and to provide information to enhance programs where appropriate. Long-term data sets are an extremely valuable resource.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Long-term	MDBC, SCA, SFA, SCMO

Objective 2. Manage river flows to enhance recruitment to Murray Cod populations.

Recruitment is defined as recruitment of reproducing adults into populations.

Justification:
This Objective supports the *Native Fish Strategy* Objective **4**: To modify flow regulation practices to facilitate native fish rehabilitation.

Increased flows appear to be important for enhanced recruitment of Murray Cod, but 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, and more research is required before appropriate environmental management policies can be developed for the benefit of MC and native fish in MDB.

Recovery Criterion:

A thorough understanding of the ecological processes relating to flows that result in improved recruitment into adult Murray Cod populations and the implementation of appropriate river flows.

Action 2.1 Determine the influence of flows on critical life history components, especially recruitment of larvae and juveniles, and movement.

Enhancing recruitment to Murray Cod populations is vital for their rehabilitation. Changes to flow regime are one of the greatest changes to Murray Cod habitats and the reinstatement of components of these regimes for environmental benefit is a key rehabilitation measure. This action will document the flow related requirements of the different life stages of Murray Cod.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Long-term	MDBC, R&D SWMA, SCA

Action 2.2 Identify and model flow regulation practices (timing of releases, volumes, rate of rise and fall etc) to maximise recruitment to rehabilitate and sustain Murray Cod populations.

River flows are regulated over a significant proportion of the MDB, hence the delivery of water is a compromise between provision of water for industry and the environment. Flow regulation and operational procedures can, however, be optimised to meet both needs. This requires the exploration of innovative and novel method of delivering this water to benefit Murray Cod. The use of models to predict outcomes is a powerful way of exploring potential outcomes.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Moderate Data dependent	Short-term Data dependent	MDBC, SWMA, SCA

Action 2.3 **Monitor population responses to prescribed flows and incorporate this knowledge into improved flow management practices.**

It is highly unlikely that the necessary information required to adequately provide flows for maximum benefit to Murray Cod populations is known. Applying prescribed flows within an adaptive experimental framework will allow this information to be obtained. This will require the monitoring of responses to flow management practices in a scientific manner within an experimental framework.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Ongoing	MDBC, SWMA, SCA

Action 2.4 **Develop and implement flow management practices to benefit recovery of Murray Cod populations.**

Actions 2.1 to 2.3 should provide information to identify appropriate key flow drivers to facilitate recruitment and movement of Murray Cod. This new knowledge should be incorporated into flow management practices to aid in the recovery of the species. It is important that these appropriate flow management practices are integrated into relevant water management plans in each State and Territory.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Hard	Long-term	MDBC, SWMA, SCA

Objective 3. **Undertake risk assessments of threats and evaluate benefits of recovery actions for each management unit.**

Justification:
This Objective supports the *Native Fish Strategy* Objectives **3**: To improve key aspects of water quality that affect native fish; and **5**: To provide adequate fish passage for native fish throughout the Basin.

Recovery Criterion:
An improved understanding and management of the main threatening processes affecting Murray Cod populations across the MDB.

Action 3.1 Test the effects of habitat manipulations such as moving snags on Murray Cod.

Many potential rehabilitation actions are theoretically plausible but remain untested. Where habitat manipulations are undertaken, these should be conducted in a manner that allows their benefits/disbenefits to be quantified.

Task assessment

Priority	Feasibility	Timeframe	Agency
Low	Easy	Short-term	MDBC, SWMA, SCA, R&D, SCMO

Action 3.2 Assess the availability and condition of riparian and instream habitat in each Spatial Management Unit, identify key areas for rehabilitation (e.g. fencing riparian habitat, resnagging) and integrate this information into relevant river health strategies or other strategies.

In order to evaluate different management options and to determine benefits from management actions, information is required for each Spatial Management Unit on the severity of degrading processes (e.g. sedimentation) and quality of existing habitats. This allows the determination of

threats and opportunities for rehabilitation and could enable identification of priorities for rehabilitation in each unit.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Moderate	Medium-term	SWMA, SLMA, SCMO, SCA

Action 3.3 Identify barriers to movement of Murray Cod populations, particularly downstream.

Adult Murray Cod move up and downstream which provides challenges to ensure that large adult pre-spawning fish can negotiate fishways and return downstream safely. Downstream drift of larvae provides recolonisation and redistribution processes for these young fish. There is a need to provide adequate passage for all life stages which undergo some form of movement. Identification of barriers and their significance in restricting movement of Murray Cod will enable prioritisation for management intervention. The workshop 'Downstream Movement of Fish in the MDB (Lintermans and Phillips 2004) noted the issue of barriers to downstream movement has received little attention although such barriers are contributing to overall decline of native fish populations. Environmental conditions including low flows, shallow water and high sediment levels can represent barriers to movement of Murray Cod; thus Actions 2.1 to 2.4 relate to this action.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Moderate	Medium-term	MDBC, SCA, SWMA, SCMO

Action 3.4 Facilitate fish passage for Murray Cod in both upstream and downstream directions.

There is a need to provide adequate passage for all life stages which undergo some form of movement. Information provided by Action 3.3 will guide the implementation of this action. In particular, the passage of large adults through fishways needs to be assessed.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Hard	Long-term	MDBC, SLMA, SCA, SWMA, SCMO

Action 3.5 Monitor the response of Murray Cod populations to improved fish passage.

Weirs can represent barriers to fish movement, both up and downstream, onto floodplains and into tributaries. They can alter flow regimes, decrease water quality, trap nutrients, sediment, adult fish, juveniles, fish eggs and larvae, as well as provide favourable conditions for exotic species such as carp. Audits have been undertaken of weirs in NSW and Victoria, and weir removal is proposed at several locations in these States. Removal of weirs is likely to be beneficial to Murray Cod populations by facilitating access to habitats and enable fish to undergo required up and downstream movement. Similarly, fish passage may be enhanced by new fishways or improved operating procedures. Monitoring of Murray cod populations following weir removal and improved fish passage should be considered. Improved fish passage will also be important for a range of other fish species.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Long-term	MDBC, SWMA, SCA, SCMO, R&D

Action 3.6 Quantify the impacts of cold water pollution on Murray Cod populations in each Spatial Management Unit.

Cold-water pollution is now recognised as a significant issue within the MDB, with downstream effects ranging for hundreds of kilometres below major impoundments. There is ample evidence that species including Murray Cod have been lost from below dams because of cold water releases e.g. in the Mitta Mitta River below Dartmouth Dam in Victoria, the Macquarie River below Burrendong Dam in NSW. Many cold water releases are around 10^{o}C, which is well below the spawning temperature of 20^{o}C required for Murray Cod. The Native Fish Strategy includes an action to document the scale, distribution and severity of thermal pollution. This is currently underway across the Basin, with monitoring of water temperatures below some dams occurring to quantify the problem, and an assessment of the changes in management required for priority dams.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Easy	Short-term	MDBC, SEPA, SWMA, SCA

Action 3.7 Develop a plan for the amelioration of cold water pollution for Murray Cod throughout the MDB, and ensure that existing infrastructure is used correctly.

The information provided from Action 3.6 will enable the development of a plan to prioritise sites for amelioration of cold water pollution for Murray cod which will also benefit other species of native fish. There is a range of solutions for addressing the problem, according to the significance of the problem, and taking into account social and economic considerations. Amelioration of cold water pollution may impact existing salmonid fisheries and aquaculture and planning should include community consultation with interested parties.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Short-term	MDBC, SEPA, SWMA, SCA

Action 3.8 Determine, plan and implement a pilot site for remedial actions for cold water pollution for Murray Cod.

This action follows on from Actions 3.6 and 3.7, and will enable clarification and documentation of the process required to implement cold water remediation at a priority site for Murray Cod. The workshop *Thermal Pollution of the MDB* (Inland Rivers Network and WWFN 2001) noted the urgent need to undertake a scientifically based pilot case to demonstrate the benefits of mitigating cold water pollution.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Long-term	MDBC, SWMA, SCA

Action 3.9 Develop and implement a monitoring program to assess the response of Murray Cod to remedial actions for cold water pollution.

Actions 3.6 to 3.8 will provide valuable information regarding sites where cold water pollution is a significant problem and how remediation actions should be implemented. These actions will need to be linked to a thorough monitoring program to clarify the effectiveness of mitigating cold water pollution. The workshop *Thermal Pollution of the MDB* (Inland Rivers Network and WWFN 2001) noted the urgent need to monitor recovery of biota and ecological processes following implementation of mitigation works.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Medium-term	MDBC, SWMA, SCA

Action 3.10 Investigate the incidence, severity, causes of, and responses to fish kills involving Murray Cod.

Fish kills are relatively common in the MDB, although in the past information has been difficult to access. In recent years there have been four fish kills involving large numbers of Murray Cod, although numbers reported killed are likely to be underestimates. Clarification of the number, severity, reasons for and responses to fish kills relating to Murray Cod will assist in improving management to avoid such fish kills in the future. This action links well with Action 3.13, and its findings could be reported to the fish kills database discussed in Action 3.12.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Short-term	MDBC, SEPA, SWMA, SLMA, SCA, SFA, SCMO

Action 3.11 Determine the status of Murray Cod populations in areas affected by fish kills and develop management responses for short-term protection and population recovery.

Many of the sites of recent fish kills are amongst the best cod populations in Victoria. While the long-term significance of fish kills is unknown, given that many populations are already diminished and fragmented, it may be great. The numbers of fish reported affected by fish kills is usually an underestimate. Assessments of the status of populations following fish kills will clarify the long-term impacts, as well as the required management actions. Population modelling may be used to estimate recovery needs and timing. Management plans for specific areas may be required. Appropriate actions may include protection of adult fish until the population has recovered, stocking of hatchery produced fish, translocation of adults, habitat rehabilitation and establishment of fishways to facilitate recolonisation opportunities. Findings should be reported to the fish kills database discussed in Action 3.12. Database should be managed by a lead State agency and linked to a central agency with regular updates.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Short-term	MDBC, SEPA, SWMA, SLMA, SCA, SCMO

Action 3.12 Establish a fish kills database and website to provide information on fish kills.

While many fish kills are undocumented, large fish kills are often very visible events and attract public and media attention. In general, these events are not managed systematically across the MDB, reasons for their occurrence are rarely identified and rehabilitation plans are not implemented. This often leads to dissatisfaction amongst stakeholders. Establishment of a fish kills database and website will enable collation of relevant information at one central location, ensuring the provision of factual and consistent information to the public. It could also contribute to the education of the public and stakeholders regarding reasons for fish kills and their potential roles in responding to fish kills. The database and website should be standardised between States and managed by a lead State agency.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Easy	Short-term	MDBC, SLMA, SCA, SFA

Action 3.13 Develop and implement consistent fish kill response protocols across the MDB and ensure appropriate linkages between agencies and knowledge sharing.

Management of fish kills within the MDB in the past has generally been variable, with initial information rarely collected systematically. A standard fish kill response protocol is required to maximise the chances of determining causes of fish kills and enable appropriate management responses before, during and after events. Data that should be collected includes fish numbers, species and behaviour, and water, sediment and biological samples. Fish kill protocols currently operate in NSW and Qld. Draft fish kill protocols are currently being developed for the MDB, ACT, SA and Victoria and require finalisation.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Short-term	MDBC, SEPA, SWMA, SLMA, SCA, SFA, SCMO

Action 3.14 Ensure that opportunities are taken to collect scientific data from fish kills.

The development and implementation of fish kill protocols will enable collection of valuable information to determine reasons for events and suitable management responses. It would be valuable to ensure that such protocols incorporate opportunities for appropriate experts to systematically collect scientific data relating to fish kills and broader environmental conditions (e.g. fish age and population structure). It is important to ensure that the correct level of expertise is included as part of the fish kills response protocol.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Ongoing	MDBC, SCA, SFA, R&D, SEPA

Action 3.15 Identify areas and conditions of high risk of poor water quality to Murray Cod populations, and develop and implement an early warning system where changes to water quality may pose a threat.

Adverse water quality has resulted in large-scale fish mortalities. Deterioration in water quality can be caused by a range of factors including low flow conditions, inappropriate use of chemicals and water releases. In most circumstances, this can be avoided by the identification of areas of high risk and conditions that increase likelihood of poor water quality and the implementation of early warning systems that trigger remedial management actions. There is a need to have preplanning procedures in place with lead agencies; this has already been initiated in some States e.g. Victoria in relation to planning for low water levels through drought. This action links well with Action 3.10.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Ongoing	SWMA, SEPA, MDBC, SCA, SCMO, SFA

Action 3.16 Quantify the loss of Murray Cod through irrigation systems and improve water diversion practices to reduce loss of fish.

It has now been identified that large numbers of Murray Cod can be lost into irrigation systems, including larvae, juveniles and adults. Options to alter water diversion practices and screening to prevent loss of fish should be investigated.

There is a need to quantify such losses and their overall impacts on Murray Cod populations.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Medium-term	SWMA, SCA

Action 3.17 Investigate the feasibility, design and implementation of potential additional Murray Cod sustainable recovery management options.

Current fishery management options for both native and introduced species already include size limit, bag limits, closed season, gear restrictions and area closures. These options are regularly reviewed by fishery agencies to ensure the sustainability of the resource. Such options need to be further explored for their effectiveness in relation to Murray Cod. The potential acceptance of conservation management options should be investigated through detailed liaison and consultation with relevant stakeholders and provision of information regarding their potential short and long-term benefits. Management options will vary from area to area.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Short-term	MDBC, SWMA, SFA, SCA, SLMO, SCMO

Action 3.18 Establish a site to trial revised Murray Cod sustainable recovery management options, identified as necessary in Action 3.17.

Once a range of sustainable recovery management options have been identified, their suitability and effectiveness should be evaluated and implemented at an appropriate site after adequate community consultation.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Short-term	MDBC, SWMA, SCA, SFA, SLMO, SCMO

Action 3.19 Determine the role and need for conservation stocking and/or translocation to restore or enhance identifiable local Murray Cod populations.

Stocking of Murray Cod is currently only undertaken for recreational purposes. There is now a need for stocking of hatchery fish to be undertaken on a conservation basis to re-establish wild, self-reproducing populations as has been undertaken for other cod species (e.g. Trout Cod). Stocking however cannot be seen as an 'easy option'. Planning of programs should include identification of clear objectives, determination of appropriate sites, the use of genetically appropriate stocks, and evaluation of their success. Options for translocations should be explored, taking into account suitable sources and numbers of fish and the impacts of their removal on existing natural populations. The impacts on, or benefits to, populations need to be quantified. This action may be appropriate for particular sites and there is a need to assess any other actions that would be appropriate to undertake at such sites. This action links well with several actions in Section 5 regarding the impact of stockings on natural populations, their contribution to recreational catch and the need to stock fish with appropriate genetic composition.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Easy	Short-term	SCA, SLMO

Action 3.20 Develop and apply a population model for Murray Cod to assess impacts of threats and recovery options.

Population modelling is a useful technique to explore and identify threats to Murray Cod as well as facilitate examination of recovery options. Threats can be explored and ranked regarding impacts to the species and the potential costs and benefits of implementing actions can be assessed. Sensitivity tools can be used to identify components of the species' ecology that may be able to be manipulated to improve the species' status. Modelling can also be used to determine population trends, growth and viability. This action links well with several actions under Objective 1.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Short-term	MDBC, SCA

Action 3.21 Establish a whole of government responsibility which defines agency roles, responsibilities and accountability for protecting Murray Cod populations in each jurisdiction.

There is currently a lack of responsibility and coordination for the protection of Murray Cod populations in many jurisdictions which may be partly explained by current resource management agency responsibilities for aquatic resources. While fisheries and conservation agencies appear to be responsible for fish, water agencies are responsible for water supply. Many fish kills appear to be related to flow regulation, and there is a potential conflict between the use of water for irrigation and domestic use and the protection of aquatic environmental assets. Clarification is required concerning departmental roles and responsibilities and determining legislation which provides the greatest protection to Murray Cod.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Short-term	CWLTH, MDBC, MCT, SFC, SCA, SCMO

Action 3.22 Encourage uptake of responsibilities and accountabilities for protecting Murray Cod populations and their habitats both within and between agencies and jurisdictions.

Information provided by Action 3.21 will clarify the roles and responsibilities of a range of agencies between jurisdictions. There will then be a need to educate staff within these agencies regarding these responsibilities

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Short-term	CWLTH, MDBC, MCT, SCA

Objective 4. Determine the habitat requirements of Murray Cod life stages and populations.

Justification:
This Objective supports the *Native Fish Strategy* Objective **1**: To repair and protect key components of aquatic and riparian habitats important for sustaining native fish populations.

Recovery Criterion:

Predictive model for potential habitat developed and tested, and habitat preference information identified and incorporated in NRM plans in the Murray-Darling Basin.

Action 4.1 **Determine the habitat use by different life stages and populations of Murray Cod and identify key habitat conditions (including water quality) to focus management actions.**

Murray Cod occurs in a variety of habitats and the significance of its usage of different habitats is not well understood. In particular, nursery habitats of post-larval fish are currently unknown. There is a need for a quantification of habitat use by both adult and juvenile fish, as habitat rehabilitation has been recognised as a key action to restore native fish populations.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Long-term	MDBC, SCA, R&D

Action 4.2 Survey and map potential habitat, using ecological and bioclimatic information that may indicate the location of important habitat areas.

Determining key habitat attributes, and their distribution and abundance, is valuable for current and future management planning. It will also assist in gaining an understanding of population establishment, dispersal and fragmentation, and how populations are likely to respond to habitat enhancement. This mapping may highlight areas appropriate to be considered as key habitats, priority management areas and for population rehabilitation. This action will be more difficult to undertake for large scale areas such as NSW.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Moderate	Short-term	MDBC, SCA, R&D

Action 4.3 Develop and implement protocols for rehabilitation of Murray Cod habitat and identify areas for rehabilitation to facilitate the expansion of Murray Cod populations into areas formerly occupied.

Rehabilitation of Murray Cod habitat relates to structural components including riparian and instream features, as well as water quality and quantity. The information obtained from Action 4.2 will aid in the identification of key habitat attributes and priority areas for rehabilitation. Protocols would enable a clear and consistent approach to addressing rehabilitation requirements.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Easy	Short-term	MDBC, SWMA, R&D, SLMA, SCMO

Action 4.4 **Develop and implement management actions to protect structural habitats in floodplain channels.**

While Murray Cod is considered a ‘main channel specialist’, it will use floodplain channels when they are inundated. The structural habitats (especially wood and bankside vegetation) in these channels require protection as these are often dry and subject to firewood collection, grazing and alienation. Protection of such habitats will benefit a range of other species.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Short-term	MDBC, SWMA, SLMA, SCMO, R&D

Action 4.5 Identify and protect habitat areas critical to the survival of Murray Cod.

Although Murray cod has a wide distribution across the MDB, populations vary in their current condition as well as the severity of threats that affect them. The concept of 'critical habitats' is included within the EPBC Act (see Appendix 6) as well as some State legislation and recognises that some sites are critical to the survival of species. Such areas may support important populations, meet essential life cycle requirements, be necessary to maintain genetic diversity and long-term evolutionary development, ensure long-term survival through reintroduction and recolonisation, be used during times of stress and be used as corridors. The identification of key habitat areas will assist in recognition of and prioritisation of areas for protection. An example of key habitat for Murray Cod may be critical waterholes in northern rivers during dry periods. The implementation of this action will benefit from data provided by Actions 4.1 to 4.4. Options for formal legislative listing can be investigated with such processes requiring consultation with management agencies and all stakeholders.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Moderate	Medium-term	MDCB, SCA, SFA, SLMA, SWMA, SCMO

Action 4.6 Develop contingency plans for issues critical to Murray Cod populations, that may occur due to unusual circumstances (e.g. drought refuges, poor water quality, isolated pools, block banks etc).

The long-term drought conditions experienced across the MDB have demonstrated the need to establish contingency plans to guide management during difficult environmental conditions. The identification of sites which become particularly significant during events such as drought will assist in directing appropriate resources to protect and maintain key sites for species such as Murray Cod.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Moderate	Medium-term	MDBC, SCA, SFA, SLMA, SWMA, SCMO

Objective 5. Manage the recreational fishery for Murray Cod in a sustainable manner while recognising the social, economic and recreational value of the fishery.

Justification:
This Objective supports the *Native Fish Strategy* Objectives **10**: To manage fisheries in a sustainable manner; **11**: To protect the natural species composition, population structure, genetic integrity and diversity of native fish communities from the adverse effects of human interventions into native fish movements and restocking; **12**: To ensure native fish populations are not threatened from aquaculture.

Recovery Criterion:

The recreational fishery for Murray Cod is managed for sustainability, there is angler and community understanding of and support for sustainable management of Murray Cod, and there is widespread compliance with recreational fisheries regulations.

Action 5.1 **Determine the total annual harvest (including catch and release, unknown, unreported and illegal catch etc) of Murray Cod across the Basin, and within Spatial Management Units.**

The National Recreational and Indigenous Fish Survey estimated a total catch of Murray Cod in the MDB of 475 000 fish, with 77% of these fish caught and released. This represents the first clear estimate of annual harvest across the species' range, although the number of fish taken

illegally and unreported has not been quantified. Illegal take may be exacerbated by the premium price paid for wild fish over cultured fish. Clarification of harvest within management units would be beneficial in quantifying the significance of recreational fishing in different areas which would in turn inform appropriate management effort such as enforcement and education in each area. While this may be a relatively difficult exercise across the Basin, it may be quite achievable for some areas.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Medium-term Ongoing	SFA, CWLTH, R&D

Action 5.2 Review existing and potential fishing regulations and modify where appropriate to ensure sustainable Murray Cod fisheries.

There is public concern about the appropriateness of current fishing regulations to ensure sustainable Murray Cod fisheries. This was demonstrated at the recent Murray Cod workshop. It would be preferable to have regulations consistent across States and Territories; this will require coordination between agencies. Regulatory reviews are undertaken recurrently by fishery management agencies. Regulations are currently under review in NSW and SA. Some fisheries regulations are standard across the Basin (e.g. daily bag limit of two fish, no difference in bag limits between streams and impoundments, closed season commencing September 1) while some vary (e.g. minimum sizes, the legality of set lines, use of maximum size limits and special bag limits). While there are some assessment and monitoring programs for stocked populations, there is no consistent approach for wild populations. Fisheries management objectives vary between States. Murray Cod is particularly susceptible to angling in months prior to the spawning season and closed seasons are instigated during this period, although the timing has been questioned for some areas and may be worthy of review. Closures during lake drawdowns associated with dry weather conditions and drought events where populations are particularly susceptible may be necessary. There is evidence of variable growth and environmental conditions across the range of Murray Cod, and together with different abundances and population structures, more site-specific regulations may be necessary as is used for salmonid fisheries.

Due to the methods used to illegally harvest fish, particularly for commercial gain, take is non-discriminatory at both species and size levels. Death rates associated with these measures can be quite high. Regulating take means that the size of fish, number of fish and gear used can be managed to such an extent that it minimises impacts on populations. However, this needs to be strengthened with meaningful penalties to act as deterrents. Review of current penalties to ensure they substantially exceed the financial gain from both the take and sale of fish is one way of dealing with this issue. High levels of community compliance are achieved through a combination of maximising voluntary compliance (primarily through education) and creating an effective deterrence (enforcement).

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Medium-term Ongoing	SFA, SCA

Action 5.3 Review the use and impacts of set-lines as a capture method for Murray Cod and modify regulations if necessary.

Set-lines are not permitted in the ACT, SA and Victoria. They are permitted for recreational anglers in NSW and Qld. In NSW, four set-lines are permitted, although not in the Murray River (Yarrawonga to Tocumwal) and impoundments (under review). In Qld, six set-lines are permitted per person. The use of set-lines captures large fish and has impacts on population viability by removing large, reproducing adults. There is considerable public opposition to the use of set-lines and their potential impacts on Murray Cod populations should be determined.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Short-term	SFA

Action 5.4 Review all compliance activities for Murray Cod across the MDB (including level and adequacy of enforcement, information provided regarding extent of illegal fishing/poaching and compliance of sale of fish) and modify as necessary to ensure Murray Cod is a priority management species to reflect the species' threatened status.

Lack of enforcement of fishing regulations is viewed by the public as a significant issue for Murray Cod in all States. A variety of regulations apply to the species although these differ between States and waters within States. Information is provided to recreational anglers via fishing guides and signage, while patrols and inspections are undertaken by fisheries officers to ensure compliance with fishing regulations. There is a common public view that enforcement penalties for breaches of compliance with Murray Cod are too light and often not enforced to the maximum, especially given its increased conservation concern. Identifying Murray Cod as a priority management species to allow a greater focus on enforcement activities and penalties would reflect a growing recognition of the importance of protection of the species. This could also be a valuable public education tool.

Fisheries agencies in Victoria, NSW, Qld and SA, with the endorsement of the Australian National Fisheries Compliance Committee and the Australian Fisheries Management Forum (2003 and 2005 Meetings), have developed and are implementing a Native Freshwater Fish Compliance Strategy (NFFCS). This ensures appropriate enforcement responses to IUU (illegal, unreported, unregulated) fishing that will assist in deterring illegal fishing activity involving Murray cod. Fisheries and Fauna protection agencies success in impacting IUU fishing will be enhanced by coordination of conservation and land management agency effort with fisheries enforcement effort. This will involve all relevant State and Federal agencies working in partnership in planning and implementation actions for the desired compliance outcomes. An active coordinated enforcement approach must be employed by relevant State agencies within the National context.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Short-term	SFA, CWLTH

Action 5.5 Provide information to politicians, magistrates and the public on the community and conservation value of Murray Cod.

There is a common public view that penalties for compliance breaches regarding Murray Cod are too light and do not reflect increased conservation concern. There is a need to provide information on the value of Murray Cod at a range of levels.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Short-term	SWMA, SCA, SFA, MDBC, SCMO

Action 5.6 Determine the contribution of stocking programs to Murray Cod populations and fishing catch.

Most stockings programs in Victoria, NSW and all stocking programs in the ACT occur in impoundments as put-and-take fisheries. Only limited stockings have occurred in Qld and ACT. The effectiveness of stocking programs has not been comprehensively determined. Stocking programs can be most valuable in the re-establishment of populations in areas where numbers

are very low or the species is extinct. Stocking however can mask true population recruitment levels.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Long-term	SFA, SCA, R&D

Action 5.7 Investigate the impact of stocking hatchery-bred Murray Cod on wild populations.

Stocking of hatchery-reared fry or fingerlings can be an important management tool in enhancing populations where natural reproduction does not occur or is limited. The addition of genetically restricted hatchery-produced fish, however, can be detrimental to the genetic diversity of wild populations. The genetic diversity of hatchery-bred fish in Victoria is known to be limited and may be more restricted in non-government hatcheries. There is currently no monitoring of genetic stocks of hatchery fish. The long-term impacts on populations, both positive and negative, need to be determined to link with the quality assurance measures.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Moderate	Medium-term	SCA, R&D

Action 5.8 Clarify the existing uptake of ethical, low-impact practices by recreational fishers, and determine how to promote these ideals more broadly among anglers and the wider community.

In recent times, there has been a growing trend amongst anglers to practice catch and release fishing, particularly for species which have a high conservation status such as Murray Cod. The rate of uptake and acceptance of catch and release methods should be determined, including issues involving animal welfare. The effect of handling fish on their long-term survival is unknown, and so the use of low-impact practices such as circular hooks and barbless lures should be emphasised as desirable fishing methods for recreational anglers.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Easy	Short-term	SFA, CWLTH

Action 5.9 Investigate damage and mortality rates of angler captured and released Murray Cod.

Studies have shown mortality of released fish can vary from low to unacceptably high and there is a need to accurately assess the impact of catch and release fishing on populations. There has been a change in public attitude towards Murray Cod in recent years, with a shift away from it being sought as a ‘trophy fish’. The National Recreational and Indigenous Fishing Survey found that a high percentage of Murray Cod (77%) are released following capture.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Medium-term	SFA, CWLTH

Action 5.10 Ensure that Murray Cod being stocked into the wild, especially where wild populations already exist, are genetically and ecologically appropriate to the location.

Stocking of Murray Cod should comply with National and State translocation policy and guidelines (e.g. *National Policy for the Translocation of Live Aquatic Organisms*; MCFFA 1999). There is some evidence that the genetic diversity of hatchery fish is currently limited, although

further investigation of hatcheries across the Basin is required. This action links well with Action 1.3 and will benefit from the results of the current PIRVic project which has determined the natural genetic structure and diversity of wild populations of Murray Cod and assessing the genetic diversity of current hatchery stocks. The capability for stocked fish to be identified/differentiated from wild fish would assist in assessing the impacts of stocking.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Short-term	SFA, SCA

Action 5.11 Implement the quality assurance measures for hatcheries outlined in 'Managing Fish Translocation and Stocking in the MDB' workshop (WWF 2003).

A comprehensive quality assurance and accreditation scheme is required for hatcheries across the Basin. This will help ensure that stockings of hatchery produced fish into the wild do not adversely affect the genetic diversity of natural populations and do not introduce unwanted biological material into the wild. A NSW Hatchery Quality Assurance Manual (Rowland and Tully 2004) was recently produced and could serve as a model.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Short-term	SFA

Objective 6. Encourage community ownership for Murray Cod conservation.

Justification:
This Objective supports the *Native Fish Strategy* Objective **13**: To ensure community and partner ownership and support for and understanding of the *Native Fish Strategy*.

Recovery Criterion:

There is broad community and partner understanding of, support for and participation in sustainable management of Murray Cod populations across the Basin.

Action 6.1 Promote Murray Cod as an icon species to raise awareness of river health and sustainability in the community.

Murray Cod is readily recognised by the public and has great potential to be an icon species given its unique biological features, large size, longevity and role as a top predator. Its decline corresponds to a general decline in river health, thus there is clear potential for it to act to a certain extent as an umbrella species and an indicator of river health and sustainability. It should be recognised however that other species may have different habitat and environmental needs.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Medium-term	CWLTH, MDBC, SWMA, SLMA, SCMO, SFA, SCA

Action 6.2 Document the significance of Murray Cod to the community, especially in Aboriginal culture and oral history, and for contemporary rural communities.

Murray Cod has a special place in Aboriginal mythology and culture, and played an important role in the lives of early explorers, pioneers and settlers. Its value and role for communities across the Basin, both in the past and present should be documented. There is currently no written record of Aboriginal interactions with cod, only verbal accounts. There are two projects

currently underway, one by NSW DPU and one by the MDBC with Aboriginal people to collect and record this information. It is important to capture knowledge through oral history to avoid information lost between generations. This action will assist in the identification of issues for the Aboriginal and rural communities to facilitate their participation and ownership in the management of Murray Cod. It will also enable the use of Aboriginal knowledge in management of the species.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Long-term	CWLTH, MDBC, SWMA, SLMA, SCMO

Action 6.3 Assess the level of public recognition, understanding and 'ownership' of Murray Cod, its ecology and the threats and management approaches to secure the long-term future of the species.

Murray Cod is undoubtedly the most recognisable fish within the MDB, and has significant economic, cultural, recreational and environmental values for Australia. The public understanding of its ecology and threats needs to be understood to assess community ownership and information needs to clarify their capability for involvement. The MCT should play a role in implementing this action.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Easy	Short-term	MDBC, SCA

Action 6.4 **Ensure the involvement of community groups (including anglers, angling clubs/associations and peak bodies and conservation groups) in the management of Murray Cod.**

Community support for Murray Cod conservation is vital to ensuring the successful outcome of recovery efforts. Community group involvement in Murray Cod conservation and sustainable recreational fishing opportunities will be maintained and expanded, where possible. Opportunities include training specific Fishcare volunteers to have a focus on and promote Murray Cod conservation and sustainable recreational fishing opportunities, and involvement of Landcare groups adjacent to rivers containing Murray Cod in habitat protection and rehabilitation. Anglers will be encouraged to participate in State angler diary programs. NFS coordinators and the MCT should play a role in implementing this action.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Medium-term Ongoing	SFA, SCA, SCMO

Action 6.5 Ensure the results of research and management on Murray Cod are publicised through a variety of mediums such as scientific meetings, journal publications and articles for the popular press, including fishing magazines and websites, and interactions with peak bodies and agencies.

Publishing research and other information on Murray Cod and management efforts is an important aspect of the recovery program. This information needs to be made available not only in scientific journals, but also in more accessible forms such as technical reports for land/water managers to be able to adapt and use the information, and in the popular literature such as magazines and media articles, to keep the community informed and build support for Murray Cod conservation, sustainable recreational fishing opportunities and management. NFS coordinators should play a role in implementing this action.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Easy	Ongoing	MDBC, SFA, SCA, SCMO, R&D

Objective 7. Manage Recovery Plan implementation.

Justification:
This Objective supports the *Native Fish Strategy* Objective **13**: To ensure community and partner ownership and support for and understanding of the *Native Fish Strategy*.

Recovery Criterion:

To have in place a broad-based recovery program for Murray Cod with the support and participation of partners including regional, State and National NRM organisations, community groups including Aboriginal, angler and environment groups, and facilitated and coordinated by the national Murray Cod Taskforce, and with improved communication between all stakeholders to share knowledge, promote understanding and develop appropriate management approaches for Murray Cod.

Including the environmental needs of Murray Cod in management of the land and water resources of the Murray-Darling Basin will equate to managing for integrity of aquatic ecosystems in the Basin and the communities dependent upon them (Kearney and Kildea 2001). The identification and control of threatening processes and protection and management of habitats for Murray Cod will potentially benefit other species and ecological communities. The adoption of broad-scale management techniques and collection of baseline data will also benefit other threatened aquatic species and communities occurring in association with Murray Cod, particularly those species with similar habitat requirements and life histories such as the Trout Cod. Murray Cod is a component species of several listed threatened aquatic communities, and management of communities requires a holistic approach at a large physical and temporal scale.

Action 7.1 Establish a long-term structure for the implementation of the Murray Cod Recovery Plan through the employment of a national Murray Cod Recovery Plan Coordinator, with involvement of the Recovery Team and the Murray Cod Taskforce.

The recovery plan includes a large number of actions across a wide area and involves many agencies. It is recognized that it would be extremely valuable to employ a coordinator to assist in the implementation of the recovery program. This coordinator, who would work closely with the Recovery Team and the Murray Cod Taskforce, could facilitate the implementation of many aspects of the plan.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Long-term	MCRT, MCT, MCRPC

Action 7.2 Develop interim targets for each Spatial Management Unit to measure progress towards the aspirational goal towards recovery at the end of the first five years.

An aspirational target of rehabilitating Murray Cod populations to 60% or better of their estimated pre-European settlement levels after 50 years of implementation has been identified. The determination of interim targets for defined areas (i.e. Spatial Management Units) is an important step when attempting to assess the effectiveness of the implementation of rehabilitation actions.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Long-term	MCRT, MCT, MCRPC, MDBC, SFA, SCA

Action 7.3 Engage with all appropriate management agencies at an early stage in the recovery process to ensure that required management actions to protect and enhance cod populations will be integrated with existing river health strategies and implemented in a timely manner.

The successful implementation of management actions requires the involvement and commitment of a range of organisations. Undertaking extensive liaison with these agencies from an early stage will be essential in fostering a sense of ownership and obligation in completing actions successfully to assist in the recovery of Murray Cod.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Short-term	MDBC, SFA, SCA, SWMA, SLMA, SCMO

Action 7.4 Compile and transfer new knowledge and research results into an appropriate form for use by management agencies to develop management practices.

As the range of actions are implemented, a large amount of new knowledge will be generated concerning ecological requirements of Murray Cod and the outcomes of improved management regimes. This new knowledge must be disseminated in an appropriate format for management staff to enable changes in management to incorporate this knowledge. Improved understanding of the species' requirements by management staff should lead to improved decision making.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Medium-term	MDBC, SFA, SCA, SWMA, SLMA, SCMO

Action 7.5 Coordinate communication and exchange of information appropriate to the recovery program at National, State and regional levels.

While implementation of recovery actions will be the responsibility of individual organisations and State agencies, there is a need for coordination of implementation, especially identification of priorities, and a mechanism for information exchange amongst principal stakeholders. The national Murray Cod Taskforce, formed from key stakeholders involved in conservation efforts and recreational fishing, is in place to provide program coordination. The MCT will operate, mainly by phone, emails and video-conferencing where required, with formal meetings held bi-annually.

Task assessment

Priority	Feasibility	Timeframe	Agency
Medium	Moderate	Ongoing	MCT

Action 7.6 Ensure integration of Murray Cod recovery with major natural resource management programs and policies in the Basin, as well as State and regional programs.

Actions of this recovery plan need to be undertaken by a range of State, Commonwealth and Community organisations. The MDB is the focus of considerable management attention, through the Murray-Darling Basin Initiative and subsidiary programs such as The Living Murray

and The Native Fish Strategy. Major environmental initiatives including plans to restore significant environmental flows to the Murray River, a shift to more natural flooding regimes, provision of fish passage over barriers and rehabilitation of riparian zones will all potentially benefit Murray Cod. There is also a range of State and regional programs that may potentially benefit the species that need to be considered. The Murray Cod represents a useful 'umbrella' species whose requirements may well encapsulate the needs of many other native species in the MDB. Integration of management efforts and monitoring the response of Murray Cod to rehabilitation programs will maximise the cost savings by achieving multiple benefits. Actions should be coordinated by the MCT.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Moderate	Ongoing	CWLTH, MDBC, SFA, SCA, SWMA, SLMA, SCMO, MCT

Action 7.7 Ensure funding submissions are organised through appropriate management agencies each year (or as required).

While a considerable amount of environmental restoration (e.g. *Living Murray* program, fishways, catchment protection, restoration of environmental flows) is occurring and is planned across the range of the Murray Cod, there are still critical gaps in knowledge, especially population responses to environmental improvement programs. External funding (such as NHT) will need to be sought to implement many of the actions contained in this Recovery Plan. For actions that occur across two or more States, coordination among the relevant management agencies is required. For other actions, individual agencies will be responsible for seeking funding for actions within their own jurisdiction. This action should be coordinated by the MCT.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Long-term	MCT, SCA, SCMO

Action 7.8 Establish a process for assessment (monitoring and evaluation) of Recovery Plan actions, including effective collation and dissemination of results.

Review and evaluation of progress towards reaching recovery objectives is an important aspect of this Recovery Plan. The employment of a national Murray Cod Recovery Plan coordinator (Action 7.1) could greatly assist in establishing an effective monitoring and evaluation program for implementation of the many recovery actions. The development of such a monitoring program could facilitate the use of consistent methods and analysis, and identify a process by which results of actions could be collated and disseminated most effectively.

Task assessment

Priority	Feasibility	Timeframe	Agency
High	Easy	Long-term	MCRT, MCT, MCRPC, R&D, SCA, SCMO, SFA

Action 7.9 Undertake a formal review and evaluation at termination of this Recovery Plan.

Review and evaluation of progress towards recovery objectives is an important part of adaptive management for threatened species conservation. The MCT and individual agencies will be responsible for regular (e.g. annually) informal review of their progress. A formal, comprehensive review and evaluation of the recovery program needs to occur at the end of the five years of implementation, to determine how effective recovery has been, and to set the process and framework for next phase of recovery. An external evaluator should be used for

the termination review, preferably someone familiar with biodiversity conservation issues, but not involved in the recovery program.

Task assessment

Priority	**Feasibility**	**Timeframe**	**Agency**
High	Easy	Short-term	CWLTH, MDBC, MCT

Table 1 - Priority, feasibility, timeframe, estimated costs and agencies/organizations which may be involved in implementation and/or reporting on implementation of recovery actions

Action	*Description*	*Priority*	*Feasibility*	*Time frame*	*Cost estimate ('000)*						*Agency/Organisation*
					Year 1	Year 2	Year 3	Year 4	Year 5	Total ('000)	
1	**Distribution & structure**										
1.1	Review population information	High	Easy	Short-term	**50**					**50**	**MDBC, SFA, SCA, R&D, SCMO**
1.2	Survey program	High	Moderate	Long-term	**400**	**400**	**400**	**400**	**400**	**2000**	**MDBC, SCA, SCMO**
1.3	Genetic composition	High	Easy	Medium-term	**100**	**100**	**100**			**300**	**MDBC, SFA, SCA**
1.4	Spatial Management units	High	Moderate	Short-term	**100**					**100**	**MDBC, SFA, SCA, SLMA, SWMA, SCMO**
1.5	Priority Spatial Management Units	High	Moderate	Long-term	**100**	**100**	**100**	**100**	**100**	**500**	**MDBC, SFA, SCA, SLMA, SWMA, SCMO**
1.6	Key habitats	High	Moderate	Long-term	**50**	**50**	**50**	**50**	**50**	**250**	**MDBC, SFA, SCA, SLMA, SWMA, SCMO**
1.7	Population structure & dynamics	Medium	Moderate	Long-term	**800**	**400**	**400**			**1600**	**SCA, R&D**
1.8	Role in fish community	Low	Hard	Long-term	**200**	**200**	**200**	**200**	**200**	**1000**	**SCA, R&D**
1.9	Reproduction ecology	High	Moderate	Long-term	**200**	**200**	**200**	**200**	**200**	**1000**	**SCA, R&D**
1.10	Model larger sizes	High	Moderate	Medium-term	**50**	**50**	**50**			**150**	**SCA, SFA**
1.11	Recruitment areas	Medium	Moderate	Medium-term	**300**	**300**	**300**			**900**	**SCA, R&D**
1.12	Population growth parameters	High	Hard	Long-term	**200**	**200**	**40**	**40**	**40**	**520**	**MDBC, SCA, R&D**
1.13	Risk management tool	High	Easy	Short-term	**100**					**100**	**SCA**
1.14	Monitoring	High	Easy	Long-term	**50**	**50**	**50**	**50**	**50**	**250**	**MDBC, SCA, SFA, SCMO**
2	**Manage river flows**										
2.1	Determine flow influence	High	Moderate	Long-term	**150**	**150**	**150**	**150**	**150**	**750**	**MDBC, R&D, SWMA, SCA**
2.2	Model flow regulation	Medium	Moderate	Short-term	**80**	**80**				**160**	**MDBC, SWMA, SCA**
2.3	Test prescribed flows	High	Easy	Ongoing	**100**	**100**	**100**			**300**	**MDBC, SWMA, SCA**
2.4	Flow management practices	High	Hard	Long-term	**60**	**60**	**60**	**60**	**60**	**300**	**MDBC, SWMA, SCA**

Action	*Description*	*Priority*	*Feasibility*	*Time frame*	*Cost estimate ('000)*						*Agency/Organisation*
					Year 1	Year 2	Year 3	Year 4	Year 5	Total ('000)	
3	**Evaluate threats and recovery**										
Priority actions											
3.1	Test habitat manipulations	Low	Easy	Short-term	**50**					**50**	**MDBC, SWMA, SCA, R&D, SCMO**
3.2	Assess habitat availability	Medium	Moderate	Medium-term	**250**	**250**	**250**			**750**	**SWMA, SLMA, SCMO, SCA**
3.3	Identify barriers to movement	Medium	Moderate	Medium-term	**160**	**160**	**160**			**480**	**MDBC, SCA, SWMA, SCMO**
3.4	Facilitate fish passage	Medium	High	Long-term	**100**	**200**	**200**	**200**	**100**	**800**	**MDBC, SLMA, SCA, SWMA, SCMO**
3.5	Monitor response to passage	High	Easy	Long-term	**100**	**100**	**100**	**50**	**50**	**400**	**MDBC, SWMA, SCA, SCMO, R&D**
3.6	Quantify cold water pollution	Medium	Easy	Short-term	**40**					**40**	**MDBC, SEPA, SWMA, SCA**
3.7	CWP amelioration plan	High	Easy	Short-term	**50**					**50**	**MDBC, SEPA, SWMA, SCA**
3.8	Pilot site for CWP amelioration	High	Moderate	Long-term	**400**	**600**	**3000**	**3000**	**3000**	**10,000**	**MDBC, SWMA, SCA**
3.9	Monitor response of CWP amel.	High	Easy	Medium-term	**80**	**80**	**80**	**80**	**80**	**400**	**MDBC, SWMA, SCA**
3.10	Fish kills investigation	High	Easy	Short-term	**100**					**100**	**MDBC, SEPA, SWMA, SLMA, SCA, SFA, SCMO**
3.11	Population assessment	High	Easy	Short-term	**150**	**150**				**300**	**MDBC, SEPA, SWMA, SLMA, SCA, SCMO**
3.12	Fish kills website & database	Medium	Easy	Short-term	**60**					**60**	**MDBC, SLMA, SCA, SFA**
3.13	Fish kills protocols	High	Easy	Short-term	**40**					**40**	**MDBC, SEPA, SWMA, SLMA, SCA, SFA, SCMO**
3.14	Scientific data collection	High	Easy	Ongoing	**50**	**50**	**50**	**50**	**50**	**250**	**MDBC, SCA, SFA, R&D, SEPA**
3.15	Water quality assessment	High	Easy	Ongoing	**100**	**100**				**200**	**SWMA, SEPA, MDBC, SCA, SCMO, SFA**
3.16	Irrigation loss	High	Moderate	Medium-term	**130**	**130**	**130**			**390**	**SWMA, SCA**
3.17	Sustainable rec mgmt options	High	Moderate	Short-term	**75**					**75**	**MDBC, SWMA, SFA, SCA, SLMO, SCMO**
3.18	Trial sust rec mgmt options	High	Moderate	Short-term	**50**	**50**	**50**			**150**	**MDBC, SWMA, SCA, SFA**

Action	*Description*	*Priority*	*Feasibility*	*Time frame*	*Cost estimate ('000)*						*Agency/Organisation*
					Year 1	Year 2	Year 3	Year 4	Year 5	Total ('000)	
											SLMO, SCMO
3.19	Conservation stocking	Medium	Easy	Short-term	**50**					**50**	**SCA, SLMO**
3.20	Population model	High	Easy	Short-term	**100**					**100**	**MDBC, SCA**
3.21	Responsibility & accountabilities	High	Moderate	Short-term	**20**					**20**	**CWLTH, MDBC, MCT, SFA, SCA, SCMO**
3.22	Uptake of responsibilities	High	Moderate	Short-term	**40**					**40**	**CWLTH, MDBC, MCT, SCA**
4	**Habitats**										
4.1	Habitat use	High	Moderate	Long-term	**130**	**130**	**130**			**390**	**MDBC, SCA, R&D**
4.2	Survey & map habitat	Medium	Moderate	Short-term	**80**	**80**	**80**			**240**	**MDBC, SCA, R&D**
4.3	Habitat rehabilitation protocols	Medium	Easy	Short-term	**50**					**50**	**MDBC, SWMA, R&D, SLMA, SCMO**
4.4	Structural habitat protection	High	Moderate	Short-term	**80**	**80**				**160**	**MDBC, SWMA, SLMA, SCMO, R&D**
4.5	Critical habitat areas	Medium	Moderate	Medium-term	**80**	**80**				**160**	**MDBC, SCA, SFA, SLMA, SWMA, SCMO**
4.6	Contingency plans	Medium	Moderate	Medium-term	**80**	**80**	**80**			**240**	**MDBC, SCA, SFA, SLMA, SWMA, SCMO**
5	**Manage recreational fisheries**										
5.1	Annual harvest	High	Moderate	Medium	**180**	**180**	**180**			**540**	**SFA, CWLTH, R&D**
5.2	Review fishing regulations	High	Easy	Medium-term	**20**		**20**			**40**	**SFA, SCA**
5.3	Review set-lines	High	Easy	Short-term	**130**	**130**	**130**			**390**	**SFA**
5.4	Review compliance activities	High	Moderate	Short-term	**50**					**50**	**SFA, CWLTH**
5.5	Information provision	High	Easy	Short-term	**50**	**50**				**100**	**SWMA, SCA, SFA, MDBC, SCMO**
5.6	Stocking contribution	High	Easy	Long-term	**100**	**100**	**100**	**100**	**100**	**500**	**SFA, SCA, R&D**
5.7	Stocking impact	Medium	Moderate	Medium-term	**100**	**100**				**200**	**SCA, R&D**
5.8	Ethical fishing practices	Medium	Easy	Short-term	**50**					**50**	**SFA, CWLTH**
5.9	Damage and mortality rates	High	Easy	Medium-term	**100**	**100**	**100**			**300**	**SFA, CWLTH**

Action	*Description*	*Priority*	*Feasibility*	*Time frame*	*Cost estimate ('000)*						*Agency/Organisation*
					Year 1	Year 2	Year 3	Year 4	Year 5	Total ('000)	
5.10	Appropriate stocking methods	High	Moderate	Short-term	**250**	**250**				**500**	**SFA, SCA**
5.11	Hatchery QA measures	High	Moderate	Short-term	**30**					**30**	**SFA**
6	**Community awareness**										
6.1	Promote Murray Cod as icon	High	Easy	Medium-term	**50**	**50**	**50**	**50**		**200**	**CWLTH, MDBC, SWMA, SLMA, SCMO, SFA, SCA**
6.2	Significance of Murray Cod	High	Moderate	Long-term	**40**	**40**	**40**	**40**	**40**	**200**	**CWLTH, MDBC, SWMA, SLMA, SCMO**
6.3	Public recognition	Medium	Easy	Short-term	**50**	**50**				**100**	**MDBC, SCA**
6.4	Community involvement	High	Moderate	Medium	**40**	**40**	**40**	**40**	**40**	**200**	**SFA, SCA, SCMO**
6.5	Publish research	Medium	Easy	Ongoing	**20**				**20**	**40**	**MDBC, SFA, SCA, SCMO, R&D**
7	**Recovery implementation**										
7.1	Implementation structure	High	Easy	Long-term	**150**	**150**	**150**	**150**	**150**	**750**	**MCRT, MCRPC, MCT**
7.2	Interim targets	High	Moderate	Short-term	**50**					**50**	**MCRT, MCRPC, MCT, MDBC, SFA, SCA**
7.3	Engage with mgmt agencies	High	Easy	Short-term	**50**	**50**				**100**	**MDBC, SFA, SCA, SWMA, SLMA, SCMO**
7.4	Knowledge for mgmt agencies	High	Moderate	Medium-term	**50**	**50**	**50**	**50**		**200**	**MDBC, SFA, SCA, SWMA, SLMA, SCMO**
7.5	Information exchange	Medium	Moderate	Ongoing	**20**	**20**	**20**	**20**	**20**	**100**	**MCT**
7.6	Integration with broader mgmt	High	Moderate	Ongoing	**50**	**50**	**50**	**50**	**50**	**250**	**CWLTH, MDBC, SFA, SCA, SWMA, SLMA, SCMO, MCT**
7.7	Funding submissions	High	Easy	Long-term	**20**	**20**	**20**	**20**	**20**	**100**	**MCT, SCA, SCMO**
7.8	Assessment process	High	Easy	Long-term	**30**	**30**	**30**	**30**	**30**	**150**	**MCRT, MCRPC, MCT, R&D, SCA, SCMO, SFA**
7.9	Program evaluation	High	Easy	Short-term	**5**	**5**	**20**	**5**	**30**	**65**	**CWLTH, MDBC, MCT**

Legend

Priority	Timeframe	Ease
Low	Short-term (<1 year)	Easy
Medium	Medium-term (1-5 years)	Moderate
High	Long-term (5+ years)	Hard

Agencies and organisations that may participate in implementation of actions and/or reporting on process of action implementation	
CWLTH	Commonwealth government agencies (e.g. DEWHA,DAFF, LWA)
LGA	Local government authorities
MCT	Murray Cod Taskforce
MDBC	Murray-Darling Basin Commission
MCRPC	Murray Cod Recovery Plan Coordinator
R&D	Cooperative research centres, CSIRO, Uni, research institutions
SCA	State conservation management agencies
SCMO	State catchment management organisation
SEPA	State environment protection authorities
SFA	State fisheries management agencies
SLMA	State land management agencies
SWMA	State water management agencies

NB: Refer to Appendix 7 for the relevant agency or organisation in each State and Territory

Costs of the Recovery Plan

The estimated cost of high priority actions in the recovery program is $24.4 million over five years (Table 2). Some of these actions are already under way or under consideration and the implementation of the recovery plan actions will be undertaken by a range of participants through a range of funding sources.

Table 2. Summary of the estimated cost of high priority and other actions outlined in Table 1. (costs are abbreviated - in $000)

Actions	Year 1	Year 2	Year 3	Year 4	Year 5	Total
High priority	4850	4225	5820	4765	4690	24350
Other	2620	2000	1690	420	340	7070
Total	7470	6225	7510	5185	5030	31420

Sustainable recovery of threatened species is dependent upon sound information facilitating knowledge-based decision-making by individuals, organisations and agencies. This needs to occur in the framework of a strong and communicative network of organisations and individuals from all levels of government, land/water managers and the community. Implementation of this Recovery Plan will involve an integrated approach by a team comprising scientists, land/water managers and community representatives to ensure the most efficient and effective use of resources.

The Recovery Plan addresses priorities under the State/Territory Partnership Agreements with the Commonwealth, where the implementation of recovery programs for nationally threatened species is a high priority under the Natural Heritage Trust. As many investment strategies for regional authorities are funded through Commonwealth agencies, it is important that the priority actions for Murray cod are reflected and implemented in these investments.

The Recovery Plan complements the objectives of State/Territory biodiversity conservation programs including the *Victorian Biodiversity Strategy* (NRE 1997) and the *ACT Nature Conservation Strategy* (ACT Government 1988). It also provides baseline long-term monitoring under the *Biodiversity Reporting Framework* established by DSE as a key process in implementation of the State Biodiversity Strategy. The Recovery Plan also complements strategic plans by regional management agencies such as the Regional Catchment Strategies (Vic), Catchment Action Plans (NSW) and the *ACT Natural Resource Management Plan 2004-2014*, and Queensland Natural Resource Management Regional Plans, that identify the conservation and management of rare/threatened species as being of high priority. It will also supplement requirements under various State biodiversity conservation legislation including the NSW *Fisheries Management Act* 1994, the ACT *Nature Conservation Act* 1980, the Victorian *Flora and Fauna Guarantee Act* 1988, relevant SA legislation (*River Murray Act* 2003, the *National Parks Act SA* 1972, the *Fisheries Act* 1982 and the *Natural Resource Management* Act 2004), Qld (*Fisheries Act* 1994) and Qld *Nature Conservation Act* 1992 that cover issues of threat abatement and action planning for threatened species.

Recovery planning for threatened fish will supplement habitat-based programs and broader environmental programs such as those of the Murray-Darling Basin Commission, especially the *Native Fish Strategy for the MDB 2003-2013* (MDBC 2004a). This Recovery Plan is a key Strategic Objective of the Strategy (SO 6 p. 14: To devise and implement recovery plans…). That Strategy includes programs for facilitating fish passage over barriers, and habitat creation/supplementation in large sections of the Murray River, and many other rivers within the Murray-Darling Basin. Other initiatives of major benefit include restoring increased flows to the Murray River, and many other rivers within the Murray-Darling Basin. These programs will have substantial benefit for the lowland native fish community, including Murray Cod, of the Murray-Darling River system.

While broad habitat-based programs such as facilitating fish passage, creation of new habitat through resnagging and restoring increased flows will have major benefit to ecological communities and many species in the Murray-Darling River system, it should be recognised that there still needs to be direct investment in specific programs for threatened species such as the Murray Cod. The monitoring of cod populations to assess their response to environmental restoration of rivers should be seen as integral to broader rehabilitation programs. However, when compared against the significant funding for nature resource management programs in the MDB, especially for water infrastructure, and the substantial social and economic importance of Murray Cod, funding specific actions in the Recovery Plan should be seen as an investment in the future for this iconic species. Investment in Murray Cod should be seen as attractive given its potential use as an umbrella species.

Funding for broad-scale (e.g. multi-regional or multi-State) actions will be sought through Basin-wide or national programs such as *The Living Murray, The Native Fish Strategy* and the Regional Competitive Component of the NHT. Some implementation arrangements will occur at the local level.

In Victoria, implementation will occur within the framework of the Regional Catchment Investment Plans (RCIP). The RCIPs are developed from the Regional Catchment Strategies (RCS), which have been prepared with extensive community and stakeholder consultation and input. Stakeholders and community are also represented on regional Implementation Committees that provide oversight for implementation of the RCIPs. Threatened species recovery, wetland management and control/amelioration of threatening processes are included as goals in the RCS. In NSW, investment strategies are prepared under Catchment Action Plans (CAPs) and implemented by relevant CMAs. In the ACT, implementation will occur within the framework of the *Draft Aquatic Species and Riparian Zone Conservation Strategy*, which will be released for public consultation in early 2006. This strategy includes conservation goals, objectives and actions for aquatic species and flora and fauna of the riparian zone, including those declared as threatened under the *Nature Conservation Act 1980*. In South Australia, implementation will occur through the MDB NRM Board Investment Strategy and where applicable, the SA's Environmental Flows Strategy for the River Murray. Any fisheries management actions would be implemented by PIRSA Fisheries. In Queensland, implementation will occur within the framework of the regional NRM groups and local catchment organisations.

The Recovery Plan acknowledges there is a need to seek specific funding opportunities, as well as ensuring integration of the species' recovery with major NRM programs and policies. Obtaining funds for Murray Cod may mean both redirection of some existing funds as well as obtaining additional money. Seeking funding opportunities for the species should be guided by the MCT, the MDBC and State agencies.

Biodiversity Benefits

The low diversity of freshwater fish species in the Murray-Darling River system heightens the importance of protection for the species-level component of biodiversity. As the major, top-level predator in the Murray-Darling River system, Murray Cod is a 'keystone species', whose activity and abundance has a major influence on the aquatic communities of the system. As such, Murray Cod will be a useful 'umbrella species', whose requirements may well encapsulate the needs of many other species in the system. Murray Cod is also likely to be seen as a 'focal species' that can be used to represent the management needs of other fish species in the river ecosystem, such as Golden Perch *Macquaria ambigua*, Silver Perch *Bidyanus bidyanus* and Freshwater Catfish *Tandanus tandanus* that maybe susceptible to similar threatening processes. Including the environmental needs of Murray Cod in management of the land and water resources of the Murray-Darling Basin will equate to managing for integrity of aquatic ecosystems in the Basin and the communities dependent upon them (Kearney and Kildea 2001). There is a need to recognise the range of native species within the Basin and their specific ecological requirements; this is consistent with the approach of many of the broad environmental programs which aim to restore functionality of particular habitat components and ecological processes.

This Recovery Plan for Murray Cod includes a number of potential biodiversity benefits for other species and ecological communities in the Murray-Darling River system in south-eastern Australia. Principally, this will be through the identification and control of threatening processes, and the protection and management of habitats. The adoption of broad-scale management techniques and collection of baseline data will also benefit other threatened aquatic species and communities occurring in association with Murray Cod, particularly those species with similar habitat requirements and life histories such as the Trout Cod. The listed threatened communities 'Lowland riverine fish community of the southern Murray-Darling Basin' in Victoria and 'Aquatic ecological community in the natural drainage system of the lower Murray River catchment' and 'Aquatic ecological community in the natural drainage system of the lowland catchment of the Darling River' in New South Wales could also benefit from implementation of this Recovery Plan.

It must be recognized that Murray Cod is a component species of these ecological communities and there is a trend for recovery plans to be directed towards communities rather than single species (Brown *et al.* 2003). Recovery planning for communities requires a holistic approach at a large physical and temporal scale. Relevant elements to consider include focusing on particular management units, restoring functionality of the ecosystem in these units, setting benchmarks by which restoration of ecosystem function can be assessed, a process to incorporate this planning within an evolving recovery plan, and inclusion of socio-economic perspectives. Ecosystem rehabilitation takes place within a social, economic and political framework.

This Recovery Plan will also provide an important public education role in aquatic conservation as Murray Cod is a major icon species, with high public recognition. As such, it has the potential to act as a 'flagship' species for highlighting broader nature conservation issues in aquatic habitats in the Murray-Darling Basin, such as habitat degradation, barriers to migration and invasive species.

This Recovery Plan for Murray Cod provides a long-term action plan for species recovery and should be viewed in the context and partnership with recovery actions for aquatic ecological communities.

Existing Conservation Measures

Much of the early work on Murray Cod revolved around its status as a valuable commercial and recreational fishery species, with studies generally focusing on catch rates, capture methods and reproductive potential, especially under aquaculture conditions. The listing of Murray Cod as Vulnerable under the EPBC Act 1999, and increasing concern for its survival, especially in light of recent extensive fish kills, has prompted a change in the management philosophy, from that of a species to be exploited, to greater recognition of its status as a threatened species (Koehn 2005b). Reflecting this concern, a number of research and management projects aimed at Murray Cod have been undertaken or are underway. At a broader level, there is recognition that the whole MDRS is under stress, and measures are underway or announced to ameliorate this impact and improve the aquatic environment, leading to the improvement in status of native fish species such as the Murray Cod. A summary of research and management initiatives for Murray Cod conservation was compiled by Lintermans (2005). Existing conservation measures for Murray Cod include:

Policy and Management

- The Murray Cod is listed as Vulnerable under National and Threatened under Victorian biodiversity conservation legislation.
- An assessment of the national status of the Murray Cod has been undertaken (Kearney and Kildea 2001).
- The MDBC hosted a major national workshop in 2004 on management issues affecting Murray Cod (Management of Murray Cod in the MDB; Lintermans and Phillips 2005), that provides management recommendations for conservation of the species.
- As a result of this workshop, a national Murray Cod Taskforce was established to advise on issues affecting Murray Cod conservation and management (Lintermans and Phillips 2005).

- Wild commercial fisheries for Murray Cod have been closed (with the exception of permitted small amount of by product species in SA in Lakes and Coorong Fishery) and there is a shift to aquaculture.
- The recreational fishery for Murray Cod is managed through implementation of various forms of legislation regarding gear, size and bag limits, seasonal closures and stockings.
- Hatchery-bred Murray Cod are regularly released to enhance or create recreational fisheries. Translocation and stocking has led to the re-establishment of cod populations in northern NSW (Rowland 2005).
- The Codwatch newsletter has been published since 1992, informing NRM managers, anglers and the broader community on issues related to Murray Cod management and conservation, as well as broader management of native fish species and aquatic and riparian habitats.
- A Native Fish Strategy for the MDB 2003-2013 has been prepared that sets the management framework for rehabilitation of native fish populations in the MDB (MDBC 2004a).
- Workshops on major issues affecting native fish populations in the MDB including 'downstream movement of fish', 'weirs', 'managing fish translocation and stocking', 'thermal pollution' and 'habitat rehabilitation' have been held and proceedings published, with recommendations that will benefit native fish including Murray Cod.
- Establishment of broad environmental programs such as The Living Murray aim to improve environmental conditions in the MDRS. The Sea to Hume Dam program is progressively installing fishways at major weirs on the Murray River and some tributaries, eventually allowing passage from the Murray mouth to Lake Hume. All Basin jurisdictions have a fishway program to improve fish passage. There are plans to increase environmental flows to the Murray River through current water saving initiatives such as piping irrigation water and decommissioning inefficient irrigation infrastructure such as Lake Mokoan (Vic).
- A review of aquatic protected areas and their potential application to habitat management areas in the MBD has recently been completed (Phillips and Butcher 2005). Options for any additional future protection of Murray cod populations or habitats should consider recommendations of this report.
- The Sustainable Rivers Audit will provide surveillance monitoring capacity for fish populations (including Murray Cod) in all river valleys in the Basin.
- There has been a review of the science and current status of Murray Cod in SA, and development of strategic initiatives for future management and research.
- A Native Fish Monitoring Program has been established to monitor the stock status of Murray Cod in the lower Murray River (SA).
- Fish surveys conducted under the Sustainable Rivers Audit will provide some data on Murray Cod populations.
- The flow requirements of native fish have been considered in the development of SA Environmental Flows Strategies and Ecological Asset Watering Plans for the lower Lakes and Chowilla Icon sights.
- Chowilla fish community study (SA).
- The removal of redundant weirs in several locations in NSW and Vic is currently being investigated.
- There are also a number of management measures including stocking and restrictions on angling that are undertaken to manage recreational angling. An Indigenous fishing strategy is also being prepared by NSW Fisheries.
- National Fisheries Compliance Committee and the Australian Fisheries Management Forum (2003 and 2005 meetings) have developed and are implementing a Native Freshwater Fish Compliance Strategy (NFFCS). This ensures appropriate enforcement responses to illegal, unreported and unregulated fishing that will assist in deterring illegal fishing activity involving Murray Cod.

Research

There is an increasing amount of research on aspects of the biology and ecology of Murray Cod. Major projects either completed or underway include:

- Determination of movement and habitat requirements of Murray Cod (Vic).
- Assessing the effects of thermal pollution on native fish in the Mitta Mitta River (Vic).
- River rehabilitation through resnagging (Vic).

- Murray River fish surveys (Vic, NSW).
- Recruitment ecology of MD fish (Vic).
- Campaspe flow manipulation project (Vic).
- Assessing effectiveness of environmental flow allocations on native fish (Vic).
- Determining the role of anabranch channels on Murray Cod (Vic).
- Determining the use of off-channel habitats by native fish (Vic).
- Survival rates of stocked fish (Vic).
- Effect of weirs on larval fish dispersal (NSW).
- Downstream movement of larval fish (NSW).
- Quantification of native fish loss in water supply offtakes (NSW).
- Use of fishways by Murray Cod, habitat use and feeding migrations (Qld).
- Impacts of native fish stocking on fish within the MDB.
- Sustaining recreational Murray Cod fisheries in MDB (Vic).

While research efforts are being undertaken by individual State agencies or institutions, most results should be transferable across the MDB. Updates on research and coordination between projects are being coordinated by the MCRF.

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Bibliography and Reading List

Abbe, T.B. and Montgomery, D.R. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. *Regulated Rivers: Research and Management* 12: 201–221.

ACT Government 1998. The ACT Nature Conservation Strategy. Conservation Series No. 15, ACT Parks and Conservation Service, Canberra.

Anderson, J. R. 1988. Status of fish – issues and discussion points. pp. 1-12. In: *Proceedings of the workshop on native fish management Canberra 16-17 June 1988.* (ed) Lawrence, B. Murray-Darling Basin Commission, Canberra.

Anderson, J.R., Morison, A.K. and Ray, D.J. 1992. Age and growth of Murray Cod, *Maccullochella peeliii* (Perciformes: Percichthyidae), in the Lower Murray-Darling Basin, Australia, from thin-section otoliths. *Australian Journal of Marine and Freshwater Research* 43: 983–1013.

Ashburner, L.D. and Ehl, A.S. 1973. *Chilodonella cyprini* (Moroff) a parasite of freshwater fish and its treatment. Bulletin of the Australian Society for Limnology 5: 3-4.

Astles, K. 2001. Overview and knowledge gaps of cold water pollution in New South Wales. Pp 30–38. In: Phillips, B. (ed) *Thermal pollution of the Murray-Darling Basin waterways*. Inland Rivers Network and World Wide Fund for Nature Australia, Sydney.

Baumgartner, L. J. 2007. Diet and feeding habits of predatory fishes upstream and downstream of a low-level weir. *Journal of Fish Biology* 70: 879-894.

Bearlin, A. A. and Tikel, D. 2003. Conservation genetics of Murray-Darling Basin fish; silver perch, Murray Cod and trout cod. Pp. 59-82. In: *Managing fish translocation and stocking in the Murray-Darling Basin. Proceedings of a workshop held in Canberra 25-26 September 2002.* World Wildlife Fund, Australia.

Berra, T.M. and Weatherley, A.H. 1972. A systematic study of the Australian freshwater serranid fish genus *Maccullochella*. *Copeia* 1: 53–64.

Blakeley, T. 2004. Screening Irrigation offtakes in the Murray-Darling Basin to reduce loss of native fish. Pp79–100. In: Lintermans, M. and Phillips, B. (eds) *Downstream movement of fish in the Murray-Darling Basin – Workshop held in Canberra, 3-4 June 2003: Statement, recommendations and supporting papers*. Murray-Darling Basin Commission, Canberra.

Blanch, S. 2001a. The way forward on weirs. Inland Rivers Network, Sydney.

Blanch, S. 2001b. Thermal pollution - what we know of the situation in Queensland, the Australian Capital Territory and South Australia. Pp. 43–44. In: Phillips, B. (ed) *Thermal pollution of the Murray-Darling Basin waterways*. Inland Rivers Network and World Wide Fund for Nature Australia, Sydney.

Brooks, A. 1999. Large woody debris and the geomorphology of a perennial river in southeastern Australia. Pp 129–138. In: Rutherfurd, I and Bartley, R. (eds) *Proceedings of the second Australian stream management conference proceedings - The challenge of rehabilitating Australia's streams*. Volume 1. (8–11 February Adelaide, South Australia).

Bunn, S., Cottingham, P., Brooks, a., Croker, K., Davies, P.M., Glaister, A., Hughes, V., Jackson, M., Koehn, J., Lake, S., Marsh, N., Nicol, S., Rutherfurd, I., Seymour, S., Treadwell, S. 2003. Managing Large Woody Debris in Australian Streams and Rivers. Riparian Land Management Technical Guide Update Number 3, May 2002. Cooperative Research Centre for Freshwater Ecology Report to Land and Water Australia.

Brown, A. M., Nicol, S. J. and Cant, B. L. 2003. *Murray-Darling fish community recovery plan.* Aquatic Ecosse Pty Ltd and Department of Sustainability and Environment, Victoria. Report for AFFA

Cadwallader, P.L. 1977. J.O. Langtry's 1949–50 Murray River investigations. *Fisheries and Wildlife Paper 13.* Fisheries and Wildlife Division, East Melbourne.

Cadwallader, P.L. 1978. Flow regulation in the Murray River System and it effect on the native fish fauna. Pp. 115–133. In: Campbell, I.C. (ed.). *Stream protection the management of rivers for instream uses*. Water Studies Centre, Chisholm Institute of Technology, East Caulfield.

Cadwallader, P.L. 1978a. Some causes of the decline in range and abundance of native fish in the Murray-Darling River system. *Proceedings of the Royal Society of Victoria* 90(1): 211–224.

Cadwallader, P. L. 1979. Distribution of native and introduced fish in the Sevens Creek river system, Victoria. *Australian Journal of Ecology* 4: 361-385.

Cadwallader, P.L. 1986. Fish of the Murray-Darling system. Pp. 679–694. In: Davies B.R. and Walker, K.F. (eds) *The ecology of river systems*. Junk Publishers, Dordrecht.

Cadwallader, P.L. and Backhouse G.N. 1983. *A guide to the freshwater fish of Victoria*. Government Printer, Melbourne.

Cadwallader, P.L. and Gooley, G.J. 1984. Past and present distributions and translocations of Murray Cod *Maccullochella peelii* and Trout Cod *M. macquariensis* (Pisces: Percichthyidae) in Victoria. *Proceedings of the Royal Society of Victoria* 96(1): 33–43.

Cadwallader, P.L. and Gooley, G.J. 1985. *Propagation and rearing of Murray cod Maccullochella peelii at the Warmwater Fisheries Station Pilot Project Lake Charlegrark*. Government Printer, Melbourne.

Cadwallader, P. and Lawrence, B. 1990. Fish. Pp 316–335. In: Mackay, N. and Eastburn, D. (eds) *The Murray*. Murray-Darling Basin Commission, Canberra.

Chotipuntu, P. 2003. Salinity sensitivity in early life stages of an Australian freshwater fish Murray cod Maccullochella peelii peelii (Mitchell 1838). PhD Thesis. University of Canberra.

Close, A. 1990. The impact of man on the natural flow regime. Pp 60–74. In: Mackay, N. and Eastburn, D. (eds) *The Murray*. Murray-Darling Basin Commission, Canberra.

Conover, D. O. and Munch, S. B. 2002. Sustaining fisheries yields over evolutionary time scales. *Science* 297: 9496.

Cottingham, P., Beckett, R., Breen, P., Feehan, P., Grace, M., Hart, B. 2001. *Assessment of the ecological risks associated with irrigation in the Goulburn Broken Catchment*. Cooperative Research Centre for Freshwater Ecology, April 2001.

Crook, D.A. and Robertson A.I. 1999. Relationships between riverine fish and woody debris: implications for lowland rivers. *Marine and Freshwater Research* 50: 941–953.

Dakin, W.J. and Kesteven, G.L. 1938. The Murray cod [*Maccullochella macquariensis* (Cuv. et Val.)]. *New South Wales State Fisheries Research Bulletin* 1: 1–18.

Dannevig, H.C. 1903. Summary of evidence regarding the Murray cod fisheries, with notes. Pp. 3–32. In: *Murray Cod Fisheries*. Government Printer, Sydney.

Davies B.R. and Walker, K.F. 1986. *The ecology of river systems*. Junk Publishers, Dordrecht.

Douglas, J. W., Gooley, G. J. and Ingram, B. A. 1994. Trout cod *Maccullochella macquariensis* (Cuvier) (Pisces: Percichthydae) resource handbook and research and recovery plan. Department of Conservation and Environment, Victoria.

Douglas, J. W., Gooley, G. J., Ingram, B. A., Murray, N. D. and Brown, L. D. 1995 Natural hybridisation between Murray cod *Maccullochella peeli peeli* (Mitchell) and trout cod *Maccullochella macquariensis* (Cuvier) (Percichthydae) in the Murray River, Australia. *Marine and Freshwater Research* 46: 729-34.

DSE 2003. *An advisory list of threatened vertebrate fauna in Victoria – 2003*. Department of Sustainability and Environment, Victoria.

Ebner, B. 2006. Murray cod as apex predator in the Murray River, Australia. *Ecology of Freshwater Fish* 15: 510-520.

ECOS Environmental Consulting Pty Ltd 2004. *Discussion paper. Fish kills and their occurrence in the Goulburn-Broken catchment.* Report prepared for Nolan ITU and EPA, Victoria

EPA 2004. *The Goulburn Weir fish kill of January 2004*. EPA Scientific Assessment Report April 2004, EPA, Victoria.

EPA 2005 *The Environmental Audit of the Goulburn River – Lake Eildon to the Murray River.* EPA, Victoria.

Faragher, R. A. and Harris, J. H. 1993. The historical and current status of freshwater fish in New South Wales. *Australian Zoologist* 29(3-4): 166-176.

Geddes, M.C. and Puckridge, J.T. 1989. Survival and growth of larval and juvenile native fish: the importance of the floodplain. Pp. 101–115. In: *Proceeding of the workshop on native fish management*. Murray-Darling Basin Commission, Canberra.

Gilligan, D. and Schiller, C. 2003. *Downstream transport of larval and juvenile fish in the Murray River*. Final Report for the National Resources Management Strategy, Project No. NRMS R7019. NSW Fisheries, Sydney.

Gippel, C.J., Finlayson, B.L. and O'Neill, I.C. 1992. The Hydraulic Basis for Snag Management. Centre for Applied Hydrology, Dept. of Civil and Agricultural Engineering: University of Melbourne.

Gippel, C.J., Finlayson, B.L. and O'Neill, I.C. 1996a. Distribution and hydraulic significance of large woody debris in a lowland Australian river. *Hydrobiologia* 318: 179–194.

Gippel, C.J., O'Neill, I., Finlayson, B.L. and Schnatz, I. 1996b. Hydraulic guidelines for the re-introduction and management of large woody debris in lowland rivers. *Regulated Rivers: Research and Management* 12: 223–236.

Gooley, G.J. 1992. Validation of the use of otoliths to determine the age and growth of Murray Cod, *Maccullochella peeliii* (Mitchell) (Percichthyidae), in Lake Charlegrark, Western Victoria. *Australian Journal of Marine and Freshwater Research* 43: 1091–102.

Gooley, G.J., Anderson, T.A. and 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: 723–728.

Graham, K. L., Lowry, M. B. and Walford, T. R. 2005. Carp in NSW: Assessment of Distribution, Fishery and Fishing Methods. Cronulla Fisheries Research Centre of Excellence. Fisheries Final Report No. 72. NSW Department of Primary Industries.

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

Harris, J. H. 2003. Fish stocking and translocation in the Murray-Darling Basin: Issues, benefits and problems. Pp. 11-27. In: Phillips, B. (ed). In: *Managing fish translocation and stocking in the Murray-Darling Basin. Proceedings of a workshop held in Canberra 25-26 September 2002.* World Wildlife Fund, Australia.

Harris, J. H. 2005. If I were the Cod God: strengthening Murray cod management. Pp. 70-72. In: Lintermans, M. and Phillips, B. (eds). *Management of Murray Cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, ACT3-4 June 2004.* Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra.

Harris, J. H. and Dixon, P. I.1988. Hybridisation between trout cod and Murray cod. *Isozyme Bulletin* 19: 39.

Harris, J.H and Gehrke, P.C. (eds) 1997. *Fish and rivers in stress: The NSW Rivers Survey*. NSW Fisheries Office of Conservation and the Cooperative Research Centre for Freshwater Ecology, Cronulla.

Harris, J.H. and Rowland, S.J. 1996. Family Percichthyidae Australian freshwater cods and basses. Pp. 150–163. In: McDowall, R.M. (ed.). *Freshwater fishes of south-eastern Australia*. Second Edition. Reed Books, Chatswood.

Henry, G. W. and Lyle, J. M. 2003 (eds) The National Recreational and Indigenous Fishing Survey. *NSW Fisheries Final Report Series No. 48 (FRDC Project No. 99/158).* p. 188. New South Wales Fisheries.

Humphries, P. 2005. Spawning time and early life history of Murray cod, *Maccullochella peelii peelii* (Mitchell) in an Australian river. *Environmental Biology of Fishes* 72(4): 393-407.

Humphries, P, King A.J. and 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.

Humphries, P., Serafini, L. G. and King, A. J. 2002. River regulation and fish larvae: variation through space and time. *Freshwater Biology* 47: 1307-1331.

Hynes, H. B. N. 1970. Ecology of running water. Liverpool UK. Liverpool University Press.

Ingram, B. A. and Rimmer, M. A. 1992. Induced breeding and larval rearing of the endangered Australian freshwater fish trout cod *Maccullochella macquariensis* (Cuvier) (Percichthydae). *Aquaculture and Fisheries Management* 24: 7-17.

Ingram, B.A., Rourke, M.L., Lade, J., Taylor, A.C. and Boyd, P. 2005. Application of genetic and reproduction technologies to Murray cod for aquaculture and conservation. Pp. 107. In: Lintermans, M. and Phillips, B. (eds). *Management of Murray cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, 3-4 June 2004*. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra. Canberra.

Inland Rivers Network and World Wide Fund For Nature 2001. *Thermal pollution in the Murray-Darling Basin waterways. Statement, recommendations and supporting papers. Proceedings of a workshop held at Lake Hume, 18-19 June 2001.* Phillips, B. (ed).

IUCN 2001. IUCN Red List categories and criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland and Cambridge.

Jacobs, T. 1990. Regulation and management of the River Murray. Pp. 38–58. In: Mackay, N. and Eastburn, D. (eds) *The Murray*. Murray-Darling Basin Commission, Canberra.

Jones, K. and Doonan, A. 2005. 2000-01 National Recreational and Indigenous Fishing Survey. South Australian Regional Information. *South Australian Fisheries Management Series Paper No. 46. July, 2005.* 99 p.

Junk, W. J., Bayley, P. B. and Sparks, R. E. 1989. The flood pulse concept in river floodplain systems. In: *Proceedings of the International Large River Symposium. Canadian Special Publication of Fisheries and Aquatic Sciences.* Pp. 110-127.

Kailola, P. J., Williams, M. J., Stewart, P. C., Reichelt, R. E., McNee, A., Grieve, C. 1993. *Australian fisheries resources.* Bureau of Rural Sciences. Department of Primary Industries and Energy, and Fisheries Research and Development Corporation. Canberra.

Kearney R.E, Davis K.M. and Beggs K.E. 1999. Issues affecting the sustainability of Australia's freshwater fisheries resources and identification of research strategies. Final Report Project No. 97/142. Fisheries Research and Development Corporation, Canberra.

Kearney R.E. and Kildea M.A. 2001. *The status of Murray cod in the Murray-Darling Basin*. Environment Australia, Canberra.

King, A.J., Humphries, P. and Lake, P.S. 2003. Fish recruitment on floodplains: the roles of patterns of flooding and life history characteristics. *Canadian Journal of Fisheries and Aquatic Sciences* 60: 773–786.

King, A. J., Tonkin, Z., and Mahoney, J. 2007. Assessing the effectiveness of environmental flows on fish recruitment in Barmah-Millewa Forest. Arthur Rylah Institute for Environmental Research. A report to the Murray-Darling Basin Commission.

Koehn, J. 1994. The cod story. In: *The geomorphology and biology of streams. Proceedings of the River Basin Management Society Summer Conference held at La Trobe University , Melbourne. 5 December 1994*.

Koehn, J. 1996. Habitats and movements of freshwater fish in the Murray-Darling Basin. Pp. 27–32. In: Banens, R.J. and Lehane, R. (eds) *Proceedings of the riverine environment forum, October 1996, Brisbane*. Murray-Darling Basin Commission, Canberra.

Koehn, J. 1997. Habitats and movements of freshwater fish in the Murray-Darling Basin. Pp. 27-32. In: Banens, R. J. and Lehane, R. (eds). *1995 Riverine Environment Research Forum. Proceedings of the inaugural Riverine Environment Research Forum of MDBC Natural Resource Management Strategy funded projects, held 4-6 October 1995 in Attwood,* Victoria. Murray-Darling Basin Commission, Canberra.

Koehn, J. 2001a. Impacts of weirs on fish. In: Blanch, S (ed) *The way forward on weirs*. Inland Rivers Network, Sydney.

Koehn, J. 2001b. Ecological impacts of cold water releases on fish and ecosystem processes. Pp 7–11. In: Phillips, B. (ed) *Thermal pollution of the Murray-Darling Basin waterways*. Inland Rivers Network and World Wide Fund for Nature Australia, Sydney.

Koehn, J.D. 2003. Riverine aquatic protected areas: protecting species, communities or ecosystem processes? In: Beumer, J.P., Grant, A. and Smith, D.C. (eds) Aquatic Protected Areas - What works best and how do we know? Proceedings of the World Congress on Aquatic Protected Areas, Cairns, Australia-August 2002. University of Queensland Printery, St. Lucia: Queensland. Pp.614-624.

Koehn, J. D., 2005a. The loss of valuable Murray cod in fish kills: a science and management perspective. Pp. 73-82. In: Lintermans, M. and Phillips, B. (eds.). *Management of Murray cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, 3-4 June 2004*. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra.

Koehn J. D. 2005b. Threats to Murray cod. Pp. 30-37. In: Lintermans, M. and Phillips, B. (eds.). *Management of Murray cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, ACT3-4 June 2004.* Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra.

Koehn, J.D. 2005c. Rehabilitation of fish habitats in the Murray-Darling Basin – where have we been and where are we going? Pp. 9-17. In: Lintermans, M., Cottingham, P. and O'Connor, R. (eds). *Native Fish Habitat Rehabilitation and Management in the Murray-Darling Basin: Statement, Rrecommendations and Supporting Papers. Proceedings of a workshop held in Albury, 10-11 February 2004.* Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra.

Koehn, J. D. 2006. The ecology and conservation management of Murray cod *Maccullochella peelii peelii.* PhD thesis. University of Melbourne.

Koehn, J.D ., Brumley, A. R., and Gehrke, P. C. 2000. *Managing Impacts of Carp*. Bureau of Rural Science, Canberra.

Koehn, J. D. and O'Connor, B. 1990. Biological information for management of native freshwater fish in Victoria. Government Printer, Melbourne.

Koehn J.D. and Harrington D.J. 2005. Collection and distribution of early life stages the Murray cod (*Maccullochella peeliii peeliii*) in components of a regulated river system. *Australian Journal of Zoology* 53, 137-144.

Koehn J.D. and Harrington D.J. 2006. Conditions and timing of the spawning of Murray cod (*Maccullochella peeliii peellii*) and the endangered trout cod (*M. macquariensis*) in regulated and unregulated rivers. *Rivers Research and Applications* 22: 327-343.

Koehn, J.D. and Morrison, A.K. 1990. A review of the conservation status of native freshwater fish in Victoria. *Victorian Naturalist* 107: 12–25.

Koehn, J. D., Doeg, T. J., Harrington, D. J. and Milledge, G. A. 1995. The effects of Dartmouth Dam on the aquatic fauna of the Mitta Mitta River. Report to the Murray-Darling Basin Commission. Arthur Rylah Institute for Environmental Research, Victoria.

Koehn, J.D. and Nicol, S. 1998. Habitat and movement requirements of fish. Pp 1–6. In: Banens, R.J. and Lehane, R. (eds) *Proceedings of the Riverine Environment Forum, October 1996, Brisbane*. Murray-Darling Basin Commission, Canberra.

Koehn, J., Nicol, S. and Fairbrother, P. 2000. *Pattern and distribution of large woody debris in the Murray River (Yarrawonga - Tocumwal)*. Final Report to the Murray-Darling Basin Commission on the snags pilot project. Department of Natural Resources and Environment, Heidelberg.

Koehn, J.D, Nicol, S.J. and Fairbrother, P.S. 2004. Spatial arrangements and physical characteristics of structural woody habitat in a lowland river in south-eastern Australia. *Aquatic Conservation: Marine and Freshwater Ecosystems*. 14: 457-464.

Koehn, J. Stuart, I. and Crook, D. 2004. Linking the ecological importance of downstream fish movements to management of Murray-Darling Basin fish populations. Pp. 67-78. In: Lintermans, M. and Phillips, B. (eds.) *Downstream Movement of Fish in the Murray-Darling Basin.- Statement, recommendations and supporting papers. Workshop held in Canberra, 3-4 June 2003:* Murray-Darling Basin Commission, Canberra.

Lake, J.S. 1959. *The freshwater fishes of New South Wales*. N.S.W. State Fisheries Research Bulletin 5.

Lake, J.S. 1967a. Rearing experiments with five species of Australian freshwater fishes. I. Inducement to spawning. *Australian Journal of Marine and Freshwater Research* 18:137–153.

Lake, J.S. 1967b. *Freshwater fish of the Murray-Darling river system*. N.S.W. State Fisheries Research Bulletin 7.

Lake, J.S. 1971. *Freshwater Fishes and Rivers of Australia*. Thomas Nelson, Sydney.

Langdon, J. S. 1989. Experimental transmission and pathogenicity of epizootic haematopoietic necrosis virus (EHNV) in redfin perch *Perca fluviatilis* L., and 11 other teleosts. *Journal of Fish Diseases* 12: 295-310.

Langdon, J. S., Humphrey, J. D., Williams, L. M., Hyatt, A. D. and Westbury, H. A. 1986. First virus isolation from Australian fish: an iridovirus-like pathogen from redfin perch *Perca fluviatilis* L. *Journal of Fish Diseases* 9: 129-135.

Langdon, J. S. and Humphrey, J. D. 1987. Epizootic haematopoietic necrosis, a new viral disease in redfin perch *Perca fluviatilis* L., in Australia. *Journal of Fish Diseases* 10: 289-297.

Lawrence, R. 1971. Habitat and economy: a historical perspective. Pp. 249–261. D.J. Mulvaney and J. Golson (Eds.), In: *Aboriginal Man and Environment in Australia.* Australian National University Press, Canberra.

Lintermans, M. 2000. The status of fish in the Australian Capital Territory: A review of current knowledge and management requirements. *Technical Report No.15.* Environment ACT, Canberra.

Lintermans, M. 2002. *Fish in the Upper Murrumbidgee Catchment: A review of current knowledge*. Environment ACT, Canberra.

Lintermans, M. 2005. Summary of management policies and fisheries regulations for Murray cod in the Murray-Darling basin. Pp. 64-69. In: Lintermans, M. and Phillips, B. (eds). *Management of Murray cod in the Murray-Darling Basin: Statement, recommendations and Supporting papers. Proceedings of a workshop held in Canberra, ACT3-4 June 2004.* Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra.

Lintermans, M. and Phillips, B. (eds) 2004. *Downstream movement of fish in the Murray-Darling Basin. Statement, recommendations and supporting papers from a workshop held in Canberra 3-4 June 2003.* Murray-Darling Basin Commission, Canberra.

Lintermans, M. and Phillips, B. (eds) 2005. *Management of Murray Cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a*

workshop held in Canberra, ACT 3-4 June 2004. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra.

Lintermans, M., Rowland, S., Koehn J., Butler, G. Simpson, B. and Wooden, I. 2005. The status, threats and management of freshwater cod species *Maccullochella* spp. in Australia. Pp. 15-29. In: Lintermans, M. and Phillips, B. (eds.). *Management of Murray cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, ACT3-4 June 2004.* Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra.

Llewellyn, L.C. 1966. Age determination of inland native fish of N.S.W. *The Fishermen* 2(4): 14–19.

Lloyd, L.N., Walker, K.F. and Hillman T.J. 1991. *Environmental significance of snags in the Murray River*. Department of Primary Industries and Energy, Land and Water Resources Research and Development Corporation, Australian Water Research Advisory Council completion report, Project 85/45, Canberra.

Lugg, A. 2000 Fish kills in NSW. Unpublished report. NSW Fisheries, Sydney

Mackay, N. 1990. Understanding the Murray. Pp viii–xix in Mackay, N. and Eastburn, D. (eds) *The Murray*. Murray-Darling Basin Commission, Canberra.

Mackay, N. and Eastburn, D. 1990. *The Murray*. Murray-Darling Basin Commission, Canberra.

Mallen-Cooper, M. and Stuart, I.G. 2003. Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system. *River Research and Applications* 19: 697–719.

MCFFA 1999 *National Policy for the Translocation of Live Aquatic Organisms*. Ministerial Council on Forestry, Fisheries and Aquaculture.. Bureau of Rural Sciences, Canberra.

McKelleher, R. 2005. An outline of the threatened species listing process under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). Pp. 62-63. In: Lintermans, M. and Phillips, B. (eds.). *Management of Murray cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, 3-4 June 2004*. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra. Canberra.

MDBC 2004a. *Native Fish Strategy for the Murray-Darling Basin 2003-2013.* Canberra, Murray-Darling Basin Commission. www.mdbc.gov.au

MDBC 2004b. *Conceptual model to guide investments for improving the status of native fish populations in the Murray-Darling Basin*. Report of the expert panel convened by the Murray-Darling Basin Commission, December 2001. Canberra, Murray-Darling Basin Commission. www.mdbc.gov.au

MDBC 2004c. *Fish Theme Pilot Audit Technical Report – Sustainable Rivers Audit*. Murray-Darling Basin Commission, Canberra. 166 p.

Morris, S.A., Pollard, D.A., Gehrke, P.C. and Pogonoski, J.J. 2000. Threatened and potentially threatened freshwater fishes of coastal New South Wales and the Murray-Darling Basin. *Report to Fisheries Action Program and World Wide Fund for Nature. NSW Fisheries Final Report Series No. 33*. 166pp.

Morrissy, N.M. 1970. Murray Cod, *Maccullochella macquariensis*, in Western Australia. *The Western Australian Naturalist*, Vol 11 (6) 130–135.

Mudie, I. M. 1961. Riverboats. Rigby Limited, Adelaide.

Muoneke, M. I. and Childress, W. M. 1994. Hooking mortality: A review for recreational fisheries. *Review of Fisheries Science* 2: 123-156.

NRFWG 1994. *Recreational Fishing in Australia: A National Policy.* National Recreational Fisheries Working Group, Department of Primary Industries and Energy, Canberra.

Natural Resource Management Ministerial Council 2005. Directions for the National Reserve System – A Partnership Approach. Natural Resource Management Ministerial Council, Canberra.

Nicol, S., Lieschke, J., Lyons, J. and Hughes, V. 2002 *Resnagging revolution. River rehabilitation through resnagging.* Final report to Agriculture, Forestry, Fisheries Australia River Rehab program. Arthur Rylah Institute for Environmental Research.

Nicol, S., Todd, C., Koehn J. and Lieschke J. 2005. How can recreational angling regulations help meet the multiple objectives of Murray cod populations. Pp. 98-106. In: Lintermans, M. and Phillips, B. (eds.). *Management of Murray Cod in the Murray-Darling Basin:*

Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, 3-4 June 2004. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra. Canberra.

Norris, R.H., Liston, P., Davies, N., Coysh., Dyer, F., Linke, S., Prosser, I. and Young, B. 2001. *Snapshot of the Murray-Darling Basin River Condition*. Report to the Murray-Darling Basin Commission, Canberra.

Park, T. 2005. A role for recreational fisherman in the management of Murray Cod: the Angler Catch database. Pp. 88-92. In: Lintermans, M. and Phillips, B. (eds). *Management of Murray Cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, 3-4 June 2004*. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra.

Park, T., Murphy, J., and Reid, D. 2005. The recreational fishery for Murray cod in the Murray-Darling Basin – Results from the National Recreational and Indigenous Fishing Survey. Pp. 93-97. In: Lintermans, M. and Phillips, B. (eds). *Management of Murray Cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, 3-4 June 2004*. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra. Canberra.

Phillips, P. J. 1972. *River Boat Days*. Lansdowne Press, Melbourne. 132 pp.

Phillips, B. 2001. *Thermal pollution of the Murray-Darling Basin waterways*. Inland Rivers Network and World Wide Fund for Nature Australia, Sydney.

Phillips, B. and Butcher, R., 2005. *Building a system of 'Habitat Management Areas' across the Murray-Darling: International and national review of freshwater 'protected areas' for conserving aquatic biodiversity and river health.* Report to Murray-Darling Basin Commission.

Pierce, B. 1990. Murray cod invade South Australia's Cooper Creek. SAFISH 7: 11-12.

Pollard, D. A. and Scott, T. D. 1966. *River and reef.* In: The Great Extermination. A. J. Marshall (ed). Pp. 95-115. William Heinemann, Melbourne.

Ramsay Smith, W. 1930. *Myths and legends of the Australian aboriginals.* Harrap, London.

Reid, D.D., Harris, J.H. and Chapman, D.J. 1997. *NSW inland commercial fishery data analysis*. FRDC Project No. 94/027.

Reynolds, J.D., Dulvy, N.K. and Roberts, C.M. 2002. Exploitation and other threats of fish conservation. Pp. 319–341. In: Hart, P.J.B and Reynolds, J.D (eds) *Handbook of Fish Biology and Fisheries Vol 2 Fisheries*. Blackwell Publishing, Melbourne.

Reynolds, L.F. 1976. Decline of native fish species in the River Murray. *SAFIC* No. 8.

Reynolds, L.F. 1983. Migration patterns of five fish species in the Murray-Darling River system. *Australian Journal of Marine and Freshwater Research* 34: 857–71.

Richarson, B.A. 1994. The human impacts on the ecology of freshwater fish in western New South Wales. Pp. 169–176. In: Lunney, D., Hand, S., Reed, P. and Butcher, D (eds.) *Future of the fauna of western New South Wales*. Royal Zoological Society of NSW, Mosman.

Rourke, M.L., McPartian H.C., Ingram B.A., Taylor A.C. 2009. Polygamy and low effective population size in a captive Murray cod (*Maccullochella peelii peelii*) population: genetic implications for wild restocking programs. *Mar Freshw Res* 60, 873-883.

Rowland, S.J. 1983a. Spawning of the Australian freshwater fish Murray cod *Maccullochella peeli* (Mitchell), in earthen ponds. *Journal of Fish Biology* 23: 525–34.

Rowland, S.J. 1983b. The hormone-induced spawning and larval rearing of Australian native freshwater fish, with particular emphasis on the golden perch, *Macquaria ambigua*. Pp. 23–32. L. F. Reynolds (Ed.), In: *Proceedings of the First Freshwater Aquaculture Workshop, February 1983.* Department of Agriculture New South Wales, Sydney.

Rowland, S.J. 1983c. Design and operation of an extensive aquaculture system for breeding warmwater fishes. Pp. 121–144. L. F. Reynolds (Ed.). In: *Proceedings of the First Freshwater Aquaculture Workshop, February 1983.* Department of Agriculture New South Wales, Sydney.

Rowland, S. J. 1985. Aspects of the biology and artificial breeding of the Murray Cod *Maccullochella peeli* and the Eastern Freshwater Cod *M. ikei* sp. nov. (Pisces: Percichthydae). PhD Thesis, Macquarie University, North Ryde.

Rowland S.J. 1988a. *Murray Cod*. Agfact, New South Wales Agriculture and Fisheries, Sydney.

Rowland, S.J. 1988b. Hormone-induced spawning of the Australian freshwater fish Murray cod, *Maccullochella* peeli (Mitchell) (Percichthyidae). *Aquaculture* 70: 371–89.

Rowland S.J. 1989. Aspects of the history and fishery of the Murray Cod, *Maccullochella peelii* (Mitchell) (Percichthyidae). *Proceedings of the Linnean Society of New South Wales* 111(3): 201–213.

Rowland, S.J. 1992. Diet and feeding of Murray cod (*Maccullochella peelii*) larvae. *Proceedings of the Linnean Society of New South Wales* 113(4): 193–201.

Rowland, S.J. 1998a. Aspects of the reproductive biology of Murray cod, *Maccullochella peelii peelii. Proceedings of the Linnean Society of New South Wales* 120:147–162.

Rowland, S.J. 1998b. Age and growth of the Australian Freshwater fish Murray cod, *Maccullochella peelii peelii. Proceedings of the Linnean Society of New South Wale*s 120: 163–180.

Rowland, S.J. 2005. Overview of the history, fishery, biology and aquaculture of Murray cod (*Maccullochella peelii peelii*). Pp. 38-61. In: Lintermans, M. and Phillips, B. (eds). *Management of Murray Cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, 3-4 June 2004*. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra. Canberra.

Rowland, S.J., and Ingram, B.A. 1991. Diseases of Australian native freshwater fishes, with particular emphasis on the ectoparasitic and fungal diseases of Murray cod (*Maccullochella peelii*), golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*). *Fisheries Bulletin No. 4,* NSW Agriculture and Fisheries.

Rowland, S. J. and Tully, P. 2004. Hatchery Quality Assurance Program for Murray cod (*Maccullochella peellii peelii*), golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*). NSW Department of Primary Industries, Sydney.

Ryan, T. and Koehn, J. 2001. The ecological impact of thermal pollution in the Mitta Mitta River. Pp. 55-57 In: Phillips, B. (ed.) Thermal pollution of the Murray-Darling waterways: Workshop held at Lake Hume,18-19 June 2001: Statement and recommendations plus supporting papers. (Inland Rivers Network and World Wide Fund for Nature).

Ryan, T., Lennie, R., Lyon, J. and O'Brien, T. 2003. *Thermal rehabilitation of the southern Murray-Darling Basin.* Final report to Agriculture, Forestry, Fisheries Australia. MD 2001 FishRehab program. Department of Sustainability and Environment.

Sherman, B., Todd, C. R. Koehn, J. D. and Ryan, T. 2007. Modelling the impact of cold water pollution and its potential mitigation on Murray cod populations downstream of Hume Dam, Australia. *Rivers Research and Applications* 23: 377-389.

Sinclair, P. 2005a. The loss of valuable Murray cod in fish kills: a community and conservation perspective. Pp. 83-87. In: Lintermans, M. and Phillips, B. (eds). *Management of Murray cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, 3-4 June 2004*. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra. Canberra.

Sinclair, P. 2005b. The values of Murray Cod: Learning invaluable lessons from King Midas. Pp. 9-14. In: Lintermans, M. and Phillips, B. (eds). *Management of Murray cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, 3-4 June 2004*. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra. Canberra.

Treadwell, S. (ed.) 1999. Managing snags and large woody debris. Pp 12–22. In: Lovett, S. and Price, P. (eds) *Riparian land management guidelines Volume two: On-ground management tools and techniques*. Land and Water Resources and Research Development Corporation, Canberra.

Treadwell, S. Koehn, J. and Bunn, S. 1999. Large woody debris and other aquatic habitat. Pp 79–96. In: Lovett, S. and Price, P. (eds) *Riparian land management guidelines Volume*

two: On-ground management tools and techniques. Land and Water Resources and Research Development Corporation, Canberra.

TSSC 2001. Recommendation on listing Murray Cod *Maccullochella peelii peelii* under the *Environment Protection and Biodiversity Conservation Act* 1999. Department of Environment and Heritage. Canberra.

Wajon, S. 1983. Hybridisation between Murray cod and trout cod in Cataract Dam, NSW. BSc. (Hons) Thesis. University of New South Wales, Sydney.

Walker, K.F. 1979. Regulated streams in Australia: the Murray-Darling. Pp. 143–163. In: Ward, J.V. and Stanford, J. A. (eds.) *The Ecology of Regulated Streams*. Plenum, New York.

Walker K.F. 1980. The downstream influence of Lake Hume on the River Murray. Pp 182–191. In: Williams W.D. (ed) *An ecological basis for water resource management*. Australian National University Press, Canberra.

Walker K.F. 1983. Impact of Murray-Darling Basin development on fish and fisheries. Pp 139–149. In: Petr, T. (ed) *Summary report and selected papers presented at the Indo-Pacific Fisheries Commission on Inland Fisheries for Planners, Manila, The Philippines, 2–6 August 1982*. FAO Fisheries Report No. 288:

Walker K.F. 1985. A review of the ecological effects of river regulation in Australia. *Hydrobiologia* 125: 111–129.

Walker K.F. 1986. The Murray-Darling River system. Pp. 631–659. In: Davies B.R. and Walker, K.F. (eds). *The ecology of river systems*. Junk Publishers, Dordrecht.

Walker K.F. 2001. A river transformed: the effects of weirs on the River Murray. Pp 7–22. In: Blanch, S. (ed) *The way forward on weirs*. Inland Rivers Network, Sydney.

Walker K.F. and Thoms, M.C. 1993. Environmental effects of flow regulation on the lower River Murray, Australia. *Regulated Rivers: Research and Management* 8: 103–119.

Webb, A. and Ryan, T. 2001. Scoping study: potential for cold water releases in Victoria. Pp38–42. In: Phillips, B. (ed) *Thermal pollution of the Murray-Darling Basin waterways*. Inland Rivers Network and World Wide Fund for Nature Australia, Sydney.

Whitley, G.P. 1937. Further ichthyological miscellanea. *Memoirs of the Queensland Museum* 11: 113–148.

Whitley, G.P. 1955. The largest (and the smallest) Australasian fishes. *Australian Museum Magazine* 11: 329–332.

Ye, Q., Jones, G.K., and 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.*

Ye, Q. and Zampatti, B. 2007. Murray Cod Stock Status – the Lower River Murray, South Australia. SARDI Aquatic Sciences Publication No. F2007-000211-1. SARDI Research Report Series No. 208.

Xenopoulos, M. A., Lodge, D. M., Alcamo, J., Marker, M., Schultze, K. and Can Vuuren, D. P. 2005. Scenarios of freshwater fish extinctions from climate change and water withdrawal. *Global Change Biology* 11: 1557-1564.

Appendix 1: Murray Cod Workshop Recommendations

Management of Murray Cod in the Murray-Darling Basin, Workshop, 3-4 June 2004, Canberra

On 3-4 June 2004, the Management of Murray Cod in the MDB workshop was held in Canberra and attended by approximately 50 people representing a cross-section of government and non-government stakeholders and experts. The workshop reviewed current knowledge of the history, status, population trends, threats and management responses. A list of priority objectives and actions were also formulated. The objectives are provided below.

Recommendations

Overarching Objective. To establish and maintain fundamental information on population structure and dynamics for Murray Cod across the Basin to guide and assess all other priority objectives.

Native Fish Strategy Objective 1. To repair and protect key components of aquatic and riparian habitats important for sustaining Murray Cod populations.

Native Fish Strategy Objective 2. To rehabilitate and protect the natural functioning of wetlands and floodplain habitats for native fish; and revive the links between terrestrial ecosystems, wetlands and rivers

Native Fish Strategy Objective 3. To improve key aspects of water quality that affect native fish

Native Fish Strategy Objective 4. To modify flow regulation practices to facilitate Murray Cod rehabilitation.

Native Fish Strategy Objective 5. To provide adequate passage for native fish throughout the Basin

Native Fish Strategy Objective 6. To devise and implement recovery plans for threatened native fish species and communities

Native Fish Strategy Objective 7. To create and implement management plans for all non-threatened native fish species and communities

Native Fish Strategy Objective 8. To control and manage Carp and other alien fish species effectively

Native Fish Strategy Objective 9. To increase understanding of fish diseases and parasites, and to protect native fish from such threats

Native Fish Strategy Objective 10. To manage recreational Murray Cod fisheries in a sustainable manner while recognizing the social, economic and recreational value of the fishery.

Native Fish Strategy Objective 11. To protect the natural species composition, population structure, genetic integrity and diversity of native fish communities from the adverse effects of human interventions into native fish movements and restocking

Native Fish Strategy Objective 12. To ensure native fish populations are not threatened from aquaculture

Native Fish Strategy Objective 13. To ensure community and partner ownership and support for and understanding of the Murray Cod management vision above.

3.3 Achieving the Priority Objectives

To pursue the priority objectives highlighted above, and their associated actions set out below, the workshop recognised that a number of institutional and policy initiatives are needed. These are as follows:

3.3.1 Institutional and policy actions

The management of Murray Cod is a multi-jurisdictional issue, and requires integrated, multi-jurisdictional responses. Actions needed to provide this approach are as follows:

1. Establish a Murray Cod Taskforce under the Murray-Darling Basin Commission's Native Fish Strategy Implementation Working Group (NFSIWG) (similar to the Fish Passage Taskforce) to provide regular advice through the NFSIWG to the Ministerial Council, the MDBC Community Advisory Taskforce (CAC) and the NFS Community Stakeholder Taskforce, on key management issues such as the:
    - size, structure, status and dynamics of Murray Cod populations;
    - levels of fishing catch from Cod populations;
    - levels of recruitment;
    - impacts of stocking efforts;
    - incidence, severity, causes of, and responses to fish kills;
    - adequacy of current management arrangements, including the impact of set lines on Murray Cod populations, appropriateness of current bag and size limits and seasonal closures and future management options;
    - feasibility, design and implementation of potential additional Murray Cod conservation measures that are widely employed in the management of other freshwater and marine fisheries. Options include closed areas, catch and release areas, identification, definition and declaration of critical habitats and management as trophy fisheries.

2. Prepare the national Recovery Plan for Murray Cod (required under the *Environment Protection and Biodiversity Conservation Act 1999* - EPBC Act) in close collaboration with the proposed Murray Cod Taskforce (see above). The Taskforce should liaise with and provide advice to the Victorian Department of Sustainability and Environment, the agency contracted by the Commonwealth Department of Environment and Heritage to prepare the Plan, in consultation with other relevant State and Territory agencies. This should ensure that the Plan reflects the priorities presented here and in the *Native Fish Strategy*, and any new research findings that address key knowledge gaps. The Recovery Plan and the priority actions identified by this workshop could then form the basis for developing a long-term plan of management for Murray Cod across the Basin.

3. While the current legislative and regulatory management arrangements for Murray Cod within the Basin States and the ACT are largely consistent, there remain anomalies. Where possible and sensible (that is, there are no biological reasons for differences continuing), such cross-jurisdictional anomalies should be investigated and rectified to provide a uniform and unambiguous administrative framework across the Basin.

4. Responses to recent fish kills involving Murray Cod have highlighted deficiencies in how agencies respond to such incidents, and there is a need to clearly identify legal responsibilities and develop, refine and implement fish kill protocols in some jurisdictions. The refinement of these fish kill protocols will need to take account of EPBC Act reporting requirements, coordinate cross-border events through the MDBC and inform other relevant bodies (such as the Natural Resource Management Ministerial Council). Jurisdictions should harmonise these protocols across the Basin States and the ACT. Recovery activities following fish kills also need to be reviewed and strengthened, with actions such as restocking, temporary closures and preparation of local recovery plans considered.

5. Noting the importance and benefits to Murray Cod populations of having appropriate water quality and flow regimes operating, each jurisdiction is urged to pursue more integrated management efforts between their fisheries and water management agencies.

For each of the priority objectives the workshop considers the following as the key actions:

3.3.2 Management information

Overarching Objective. To establish and maintain fundamental information on population structure and dynamics for Murray Cod across the Basin to guide and assess all other priority objectives.

Priority actions

6. Critically review and synthesise existing information on the population structure, status and dynamics of Murray Cod (Step 1); develop (Step 2) and implement (Step 3) a Basin-wide plan to measure and monitor these parameters at the Basin and management unit scale. [Note this action is indicated for attention by the proposed Murray Cod Taskforce – Action 1 above]

7. Use the measures and monitoring of Murray Cod population structure, status and dynamics (as collected under steps 1-3 above) to re-assess the priority and activities conducted under the 13 *Native Fish Strategy* objectives.

3.3.3 Habitat repair and protection

Native Fish Strategy Objective 1. To repair and protect key components of aquatic and riparian habitats important for sustaining Murray Cod populations.

Priority actions:

8. Identify appropriate management units for Murray Cod (jurisdictional, habitat zones, genetic Evolutionary Significant Management Units) across their range and then apply these to:
    a. map Murray Cod habitats and from among these identify the critical habitats;
    b. identify, prioritise and address the threats to Murray Cod within each management unit;
    c. develop, cost and implement a recovery plan for habitat and threat reduction in each management unit (valley, region, State). Plans should identify areas for rehabilitation to facilitate the expansion of Murray Cod population into areas formerly occupied;
    d. monitor the impact of these recovery plans.

9. Ensure that habitat rehabilitation for Murray Cod includes actions to see important native prey species retained or restored.

10. Further promote Catchment Management Authorities (and the equivalent regional natural resource management bodies) to factor into their catchment plans and associated investment strategies actions to improve habitat conditions for Murray Cod.

3.3.4 Flow regulation

Native Fish Strategy Objective 4. To modify flow regulation practices to facilitate Murray Cod rehabilitation.

Priority actions:

11. Develop and implement protocols for managing flow regimes (the timing of releases, volumes, rate of rise and fall etc) to rehabilitate Murray Cod populations.

12. Monitor the response of Murray Cod (and other native species) to flow management activities and incorporate such knowledge into improved flow management practices.

3.3.5 Managing recreational fisheries

Native Fish Strategy Objective 10. To manage recreational Murray Cod fisheries in a sustainable manner while recognizing the social, economic and recreational value of the fishery.

There is some evidence based on limited scientific data, reports from recreational anglers and articles in popular fishing magazines and newspapers to suggest that there has been a recovery

of Murray Cod stocks in some New South Wales waters. However, the extent of this recovery, the role of fish stocking programs and other causative factors, and the actual status of wild populations of Murray Cod are unknown and need to be determined.

Priority actions:

13. Through the proposed Murray Cod Taskforce (see action 1 above), assess the appropriateness of current or potential fishing regulations and practices such as angling methods, bag and size limits and seasonal closures.

14. Develop and implement a Basin-wide management plan for Murray Cod (see action 2 above) that has reference points built in that result in appropriate 'precautionary approach'-based management responses.

15. Adopt, enforce and regularly evaluate rigorous harvest controls for Murray Cod for each management unit (see action 8 above) based on the best available information.

16. Adopt the 'best available practice' stocking policies and practices (see Phillips. B, 2003: *Managing Fish Translocation and Stocking in the Murray-Darling Basin*).

3.3.6 Community and partner ownership

Native Fish Strategy Objective 13. To ensure community and partner ownership and support for and understanding of the Murray Cod management vision above.

It is important to pursue ways to encourage public ownership of the issues affecting Murray Cod and seek to gain a broader connectedness to rivers from among the community, rural, urban, city and country dwellers.

Priority actions:

17. Improve communication between all stakeholders (such as managers, scientists, Indigenous communities, regional communities, local governments, regional bodies, State government agencies, environmental groups, recreational. fishers etc) to share knowledge, promote understanding and develop appropriate management approaches for Murray Cod. More specifically:
    a. through stakeholder consultation, foster suitable fishing competition policies to ensure sustainable angling practices;
    b. compile and widely disseminate available information on Cod habitat needs to support remedial actions being undertaken by a range of stakeholders; promote community reporting of illegal activities and threats to Murray Cod and investigate the establishment of 'river sentinels' to monitor river/fish health and assist in prevention of illegal activities.
    c. involve the community in the development and implementation of action statements and recovery plans for Murray Cod (see various actions above).

18. Indigenous participation in the management of Murray Cod is essential, with Indigenous issues and participation considered as part of the mainstream, rather than peripheral or separate. To assist this happening, provide mechanisms for greater communication and interaction between Indigenous stakeholders and the MDBC's working groups/committees such as the Community Advisory Committee and the Fish Management and Science Committee.

19. Promote the Murray Cod as an icon species and indicator of river health and sustainability through:
    - the development and wide dissemination of a range of awareness raising and educational tools about the values and significance of the species plus the threats to it and management responses needed by stakeholder groups to protect and rehabilitate Cod populations;
    - using well known (credible) human icons to promote the river icon, the Murray Cod, and to act as champions for the issues and community responses being sought.

- investigation of the possible application of the 'tidy town' concept (like '*Welcome to Sustainable Cod Country*' or '*We care about Murray Cod, and are doing something about it*') to raise awareness and promote on-ground actions;

4. Key research needs:

For each of the priority objectives above, the workshop identified the key research needs as set out below. A broader consideration of research priorities was undertaken during the workshop and the results of this informal survey of views are provided as Appendix.

4.1 Management information

The overarching objective focused on the collection and maintenance of information needed to guide and inform management actions. The priorities in this regard where indicated as follows:

1. Determine the genetic composition of Murray Cod populations throughout the Basin.
2. Determine the structure (age, size, spatial connectivity) and dynamics of Cod populations in each management unit.

4.2 Habitat repair and protection

3. Undertake habitat mapping for Murray Cod with identification of critical habitats to focus management actions.
4. Establish the appropriate scales (spatial and temporal) for rehabilitation investments.
5. Develop an improved understanding of the habitat requirements for all life stages of Murray Cod.
6. Determine the habitat requirements of the important native prey species for Murray Cod, at all life stages.

4.3 Flow regulation

7. Establish the links between flows and Murray Cod recruitment.
8. Determine the flow requirements of all life stages (eggs, larvae, juveniles, adults) and critical life history components (movement, spawning, recruitment) of Murray Cod.
9. Develop an improved understanding of the impact of water quality on Murray Cod.

4.4 Managing recreational fisheries

10. Investigate the effectiveness and threats posed by stocking in the maintenance of wild Murray Cod populations.
11. Investigate reports suggesting that Murray Cod numbers may be recovering in some areas in NSW, although not to early-European levels.
12. Establish the total annual harvest (including catch and catch and release, unknown, unreported and illegal catch etc) of Murray Cod across the Basin, and within prescribed management units.

4.5 Community and partner ownership

13. Define the level of public recognition, understanding and 'ownership' of Murray Cod, their ecology and the threats and management approaches to secure the long-term future of the species.
14. Document the significance of Murray Cod in Indigenous culture and oral history.
15. Clarify the existing uptake of ethical practices by recreational fishers, and how to promote these ideals more broadly among anglers and the wider community.

Appendix 2: Objectives of the MDBC Native Fish Strategy

1. Aquatic habitat

Objective: To repair and protect key components of aquatic and riparian structural habitat that sustain native fish.

Sub-objective: To protect important areas and attributes of in-stream structural habitat and, where necessary, rehabilitate native aquatic vegetation and other structural features of habitat to maintain fish-habitat diversity.

Sub-objective: To protect important areas and attributes of riparian habitat and, where necessary, rehabilitate riparian vegetation and other structural features of riparian habitat to maintain fish-habitat diversity.

2. Floodplain and wetland habitats

Objective: To rehabilitate the natural functioning of wetlands and floodplain habitats for fish, and revive the linkages between wetlands and rivers.

Sub-objective: Implementation of best management practices for floodplains and wetlands, incorporating planning principles for ecologically functional riverine corridors at all scales.

Sub-objective: To provide knowledge needed to revive ecological processes in floodplains, temporary channels and wetlands for the benefit of native fish.

3. Water quality

Objective: To improve key aspects of water quality that affect native fish.

Sub-objective: To prevent and mitigate the impact of poor water quality on native fish in the Basin.

Sub-objective: To raise community awareness about the role and importance of water quality and its ecological significance for native fish.

4. Flow regulation

Objective: To modify flow regulation practices so that they facilitate native fish rehabilitation.

Sub-objective: To protect riverine ecological functions necessary to sustain native fish communities by reinstating flow regimes that mimic natural hydrographic patterns.

Sub-objective: To increase the availability of water to the environment.

Sub-objective: To maintain and reinstate flow regimes that will improve the timely watering of targeted wetlands and river zones to rehabilitate and maintain native fish communities.

5. Fish passage

Objective: To provide adequate passage for native fish throughout the Basin.

Sub-objective: To reinstate fish passage in both upstream and downstream directions and in all seasons at artificial barriers throughout the Murray-Darling Basin

Sub-objective: To reinstate and maintain fish passage in both upstream and downstream directions at environmental impediments in all seasons throughout the Murray-Darling Basin.

6. Threatened species and communities and conservation zones

Objective: To devise and implement recovery plans for threatened fish species and communities.

7. Non-threatened fish species

Objective: To create and implement management plans for all non-threatened fish species and communities.

8. Alien fish

Objective: To control and manage carp and other alien fish species effectively.

Sub-objective: To implement strategies to control or eradicate existing alien species.

Sub-objective: To prevent the introduction and establishment of new alien species and to develop strategies for management.

Sub-objective: To prevent the escape of aquaculture species by ensuring that all aquaculture facilities are secure.

9. Diseases and parasites

Objective: To increase understanding of fish diseases and parasites and to protect native fish from them.

10. Sustainable fishing

Objective: To manage recreational and commercial fisheries in a sustainable way.

Sub-objective: To protect riverine fish populations from the adverse impacts of fishing.

11. Fish translocation and stocking

Objective: To protect the natural species composition, population structure, genetic integrity and diversity of native fish communities from the adverse effects of fish translocation and stocking.

12. Aquaculture

Objective: To ensure that native fish populations benefit from aquaculture.

13. Knowledge generation and transfer

Objective: To ensure that the community and stakeholders understand and support the Native Fish Management Strategy.

Sub-objective: To engage the community and stakeholders with implementation of the Native Fish Management Strategy through an effective communication strategy.

Sub-objective: To initiate relevant scientific research which will provide new knowledge to support management actions in an adaptive context.

Sub-objective: The objectives, actions and targets of the Strategy are monitored and evaluated to measure its success and provide a basis for adaptive management.

Appendix 3: Murray Cod Taskforce – Terms Of Reference and Membership

1. Under the umbrella of the MDBC's Native Fish Strategy Implementation Working Group (NFSIWG), provide regular advice through the NFSIWG to the Ministerial Council, the MDBC Community Advisory Group and the NFS Community Stakeholder Taskforce on key issues such as:
   - the identity, size, structure and dynamics of cod populations;
   - the level of fishing catches from cod populations;
   - levels of recruitment;
   - impacts of stocking efforts;
   - impacts of, and mitigation options for, thermal pollution;
   - habitat management options and priorities;
   - community liaison and involvement in the management of Murray Cod;
   - the incidence, severity, causes of, and responses to fish kills;
   - the adequacy of current management arrangements, including the impact of set lines on Murray Cod populations; appropriateness of current bag and size limits and seasonal closures; and future management options;
   - the feasibility, design and implementation of potential additional Murray Cod management measures that are widely employed in the conservation of other freshwater and marine fisheries such as closed areas; catch and release areas; identification, definition and declaration of critical habitats; and trophy fisheries;
   - measures to further promote Murray Cod as an icon species.
2. Liaise with and provide advice to the Victorian Department of Sustainability and Environment regarding the National Recovery Plan for the Murray Cod in consultation with relevant State and Territory agencies and other regional natural resource management groups and catchment management organisations, thus ensuring that the plan reflects the priorities in the *Native Fish Strategy*, and any new research findings that address key knowledge gaps.
3. Identify, and develop project briefs for, research priorities to assist decision-making in the management of Murray Cod.

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Appendix 4a: Summary of Recovery Actions by Priority

Action Number	Action Title	Priority
High		
1.1	Review and synthesize published information on the population structure, status and dynamics of Murray Cod populations across the Basin.	High
1.2	Identify gaps in distribution and population data and develop and implement a survey program to obtain data to address this.	High
1.3	Determine the genetic composition of Murray Cod populations throughout the Basin.	High
1.4	Identify appropriate Spatial Management Units for Murray Cod management across their range	High
1.5	Prioritise the Spatial Management Units that require urgent or specific management actions: monitor and maintain these units	High
1.6	Identify, protect and repair key aquatic and riparian habitats for Murray Cod in each Spatial Management Unit.	High
1.9	Investigate the current reproductive status, age/size fecundity relationships, age at first reproduction, recruitment levels and longevity of key populations of Murray Cod.	High
1.10	Model the significance of larger size classes to recruitment and sustainability of Murray Cod populations, and develop management strategies to achieve sustainability where skewed population structure is unsustainable.	High
1.12	Identify and quantify the environmental parameters that drive recruitment and population growth, especially age-specific survivorships.	High
1.13	Develop appropriate decision support tools and models that allow the future management actions for Murray Cod to be evaluated within a risk management framework.	High
1.14	Develop and implement an integrated, long-term monitoring program for assessing the recovery of Murray Cod populations in each Spatial Management Unit.	High
2.1	Determine the influence of flows on critical life history components, especially recruitment of larvae and juveniles and movement.	High
2.3	Monitor population responses to prescribed flows and incorporate this knowledge into improved flow management practices.	High
2.4	Develop and implement flow management practices to benefit recovery of Murray Cod populations.	High
3.5	Monitor the response of Murray Cod populations to improved fish passage.	High
3.7	Develop a detailed plan for the amelioration of cold water pollution for Murray Cod throughout the MDC and ensure that existing infrastructure is used correctly.	High
3.8	Determine, plan and implement a pilot site for remedial actions for cold water pollution for Murray Cod.	High
3.9	Develop and implement a monitoring program to assess the response of Murray Cod to remedial actions for cold water pollution.	High

Action Number	Action Title	Priority
3.10	Investigate the incidence, severity, causes of, and responses to fish kills involving Murray Cod.	High
3.11	Determine the status of Murray Cod populations in areas affected by fish kills and develop management responses for short-term protection and population recovery.	High
3.13	Develop and implement consistent fish kill response protocols across the MDB and ensure appropriate linkages between agencies and knowledge sharing.	High
3.14	Ensure that opportunities are taken to collect scientific data from fish kills.	High
3.15	Identify areas and conditions of high risk of poor water quality to Murray Cod populations and develop and implement an early warning system where changes to water quality may pose a threat.	High
3.16	Quantify the impact of loss of Murray Cod through irrigation systems and improve water diversion practices to reduce loss of fish	High
3.17	Investigate the feasibility, design and implementation of potential additional Murray Cod sustainable recovery management options.	High
3.18	Establish a site to trial revised Murray Cod sustainable recovery management options, identified as necessary in Action 3.17.	High
3.21	Establish a whole of government responsibility which defines agency roles, responsibilities and accountability for protecting Murray Cod populations in each jurisdiction.	High
3.22	Encourage uptake of responsibilities and accountabilities for protecting Murray Cod populations and their habitats both within and between agencies and jurisdictions.	High
4.1	Determine the habitat use by different life stages and populations of Murray Cod and identify key habitat conditions (including water quality) to focus management actions.	High
4.4	Develop and implement management options to protect structural habitats in floodplain channels.	High
5.1	Determine the total annual harvest (including catch and release, unknown, unreported and illegal catch etc) of Murray Cod across the Basin, and within Spatial Management Units.	High
5.2	Review existing and potential fishing regulations and modify where appropriate to ensure sustainable Murray Cod fisheries.	High
5.3	Review the use and impacts of set-lines as a capture method for Murray Cod and modify regulations where necessary.	High
5.4	Review all compliance activities for Murray Cod across the MDB (including level and adequacy of enforcement, information provided regarding extent of illegal fishing/poaching and compliance of sale of fish) and modify as necessary to ensure Murray Cod is a priority management species to reflect the species' threatened status.	High
5.5	Provide information to politicians, magistrates and the public on the community and conservation value of Murray Cod.	High
5.6	Determine the contribution of stocking programs to Murray Cod populations and fishing catch.	High
5.9	Investigate damage and mortality rates of angler captured and released Murray Cod	High

Action Number	Action Title	Priority
5.10	Ensure that Murray Cod being stocked into the wild, especially where wild populations already exist, are genetically and ecologically appropriate to the location.	High
5.11	Implement the quality assurance measures for hatcheries outlined in 'Managing Fish Translocation and Stocking in the MDB' workshop (WWF 2003)	High
6.1	Promote Murray Cod as an icon species to raise awareness of river health and sustainability in the community	High
6.2	Document the significance of Murray Cod to the community, especially in Indigenous culture and oral history, and for contemporary rural communities.	High
6.4	Ensure the involvement of community groups (including anglers) in the management of Murray Cod.	High
7.1	Establish a long-term structure for the implementation of the Murray Cod Recovery Plan through the employment of a national Murray Cod Recovery Plan coordinator, with involvement of the Recovery Team and the Murray Cod Taskforce	High
7.2	Develop interim targets for each Spatial Management Unit to measure progress towards the aspirational goal towards recovery at the end of the first five years	High
7.3	Engage with all appropriate management agencies at an early stage in the recovery process to ensure that required management actions to protect and enhance cod populations will be implemented in a timely manner.	High
7.4	Compile and transfer new knowledge and research results into an appropriate form for use by management agencies to develop management practices.	High
7.6	Ensure integration of Murray Cod recovery with major natural resource management programs and policies in the Basin	High
7.7	Ensure funding submissions are organized through appropriate management agencies each year (or as required)	High
7.8	Establish a process for assessment (monitoring and evaluation of Recovery Plan actions, including effective collation and dissemination of results	High
7.9	Undertake a formal review and evaluation at the termination of this Recovery Plan	High
Medium		
1.7	Determine the structure (age, size, spatial connectivity), dynamics, movement, dispersal and migration levels of Murray Cod populations in and between each Spatial Management Unit.	Medium
1.11	Identify key recruitment areas in each Spatial Management Unit.	Medium
2.2	Identify and model flow regulation practices (timing of releases, volumes, rate of rise and fall etc) to maximise recruitment to rehabilitate and sustain Murray Cod populations.	Medium
3.2	Assess the availability and condition of riparian and instream habitat in each Murray Cod Spatial Management Unit, identify key areas for rehabilitation (e.g. fencing riparian habitat, resnagging and integrate this information into relevant river health strategies or other strategies.	Medium
3.3	Identify barriers to movement of Murray Cod populations, particularly downstream.	Medium

Action Number	Action Title	Priority
3.4	Facilitate fish passage for Murray Cod both in upstream and downstream directions.	Medium
3.6	Quantify the impacts of cold water pollution on Murray Cod populations in each Spatial Management Unit.	Medium
3.12	Establish a fish kills database and website to provide information on fish kills.	Medium
3.19	Determine the role and need for conservation stocking and/or translocation to restore or enhance identifiable local Murray Cod populations.	Medium
3.20	Develop and apply a population model for Murray Cod to assess impacts of threats and recovery options.	Medium
4.2	Survey and map potential habitat, using ecological and bioclimatic information that may indicate the location of important habitat areas.	Medium
4.3	Develop and implement protocols for rehabilitation of Murray Cod habitat and identify areas for rehabilitation to facilitate the expansion of Murray Cod populations into areas formerly occupied.	Medium
4.5	Identify and protect critical habitat areas for Murray Cod.	Medium
4.6	Develop contingency plans for issues critical to Murray Cod populations that may occur due to unusual circumstances (e.g. drought refuges, poor water quality, isolated pools, block banks etc).	Medium
5.7	Investigate the impact of stocking hatchery-bred Murray Cod on wild populations.	Medium
5.8	Clarify the existing uptake of low-impact practices by recreational fishers, and determine how to promote these ideals more broadly among anglers and the wider community.	Medium
6.3	Assess the level of public recognition, understanding and 'ownership' of Murray Cod, its ecology and the threats and management approaches to secure the long-term future of the species.	Medium
6.5	Ensure the results of research and management on Murray Cod are publicized through a variety of mediums such as scientific meetings, journal publications and articles for popular press, including fishing magazines and websites, and interactions with peak bodies and agencies.	Medium
75	Coordinate communication and exchange of information appropriate to the recovery program at National, State and regional levels	Medium
Low		
1.8	Investigate the role and relationships of Murray Cod within the fish community	Low
3.1	Test the effects if habitat manipulations such as moving snags on Murray Cod	Low

Appendix 4b: Summary of Recovery Actions by Ease of Implementation

Action Number	Action Title	Ease
Easy		
1.1	Review and synthesize published information on the population structure, status and dynamics of Murray Cod populations across the Basin.	Easy
1.3	Determine the genetic composition of Murray Cod populations throughout the Basin.	Easy
1.12	Identify and quantify the environmental parameters that drive recruitment and population growth, especially age-specific survivorships.	Easy (DD*)
1.13	Develop appropriate decision support tools and models that allow the future management actions for Murray Cod to be evaluated within a risk management framework.	Easy
1.14	Develop and implement an integrated, long-term monitoring program for assessing the recovery of Murray Cod populations in each Spatial Management Unit.	Easy
3.1	Test the effects if habitat manipulations such as moving snags on Murray Cod	Easy
3.5	Monitor the response of Murray Cod populations to improved fish passage.	Easy
3.6	Quantify the impacts of cold water pollution on Murray Cod populations in each Spatial Management Unit.	Easy
3.7	Develop a detailed plan for the amelioration of cold water pollution for Murray Cod throughout the MDC and ensure that existing infrastructure is used correctly.	Easy
3.9	Develop and implement a monitoring program to assess the response of Murray Cod to remedial actions for cold water pollution.	Easy
3.10	Investigate the incidence, severity, causes of, and responses to fish kills involving Murray Cod.	Easy
3.11	Determine the status of Murray Cod populations in areas affected by fish kills and develop management responses for short-term protection and population recovery.	Easy
3.12	Establish a fish kills database and website to provide information on fish kills.	Easy
3.19	Determine the role and need for conservation stocking and/or translocation to restore or enhance identifiable local Murray Cod populations.	Easy
3.20	Develop and apply a population model for Murray Cod to assess impacts of threats and recovery options.	Easy
3.13	Develop and implement consistent fish kill response protocols across the MDB and ensure appropriate linkages between agencies and knowledge sharing.	Easy
3.14	Ensure that opportunities are taken to collect scientific data from fish kills.	Easy
3.15	Identify areas and conditions of high risk of poor water quality to Murray Cod populations and develop and implement an early warning system where changes to water quality may pose a threat.	Easy

Action Number	Action Title	Ease
4.3	Develop and implement protocols for rehabilitation of Murray Cod habitat and identify areas for rehabilitation to facilitate the expansion of Murray Cod populations into areas formerly occupied.	Easy
5.2	Review existing and potential fishing regulations and modify where appropriate to ensure sustainable Murray Cod fisheries.	Easy
5.3	Review the use and impacts of set-lines as a capture method for Murray Cod and modify regulations where necessary.	Easy
5.5	Provide information to politicians, magistrates and the public on the community and conservation value of Murray Cod.	Easy
5.6	Determine the contribution of stocking programs to Murray Cod populations and fishing catch.	Easy
5.8	Clarify the existing uptake of low-impact practices by recreational fishers, and determine how to promote these ideals more broadly among anglers and the wider community.	Easy
5.9	Investigate damage and mortality rates of angler captured and released Murray Cod.	Easy
6.1	Promote Murray Cod as an icon species to raise awareness of river health and sustainability in the community.	Easy
6.3	Assess the level of public recognition, understanding and 'ownership' of Murray Cod, its ecology and the threats and management approaches to secure the long-term future of the species.	Easy
6.5	Ensure the results of research and management on Murray Cod are publicized through a variety of mediums such as scientific meetings, journal publications and articles for popular press, including fishing magazines and websites, and interactions with peak bodies and agencies.	Easy
7.1	Establish a long-term structure for the implementation of the Murray Cod Recovery Plan through the employment of a national Murray Cod Recovery Plan Coordinator, with involvement of the Recovery Team and the Murray Cod Taskforce.	Easy
7.3	Engage with all appropriate management agencies at an early stage in the recovery process to ensure that required management actions to protect and enhance cod populations will be implemented in a timely manner.	Easy
7.7	Ensure funding submissions are organized through appropriate management agencies each year (or as required).	Easy
7.8	Establish a process for assessment (monitoring and evaluation) of the Recovery Plan actions, including effective collation and dissemination of results.	Easy
7.9	Undertake a formal review and evaluation at the termination of this Recovery Plan.	Easy
Moderate		
1.2	Identify gaps in distribution and population data and develop and implement a survey program to obtain data to address this.	Moderate
1.4	Identify appropriate Spatial Management Units for Murray Cod management (jurisdictional, habitat zones, genetic Evolutionary Significant Management Units) across their range.	Moderate
1.5	Prioritise the Spatial Management Units that require urgent or specific management actions: monitor and maintain these units.	Moderate

Action Number	Action Title	Ease
1.6	Identify, protect and repair key aquatic and riparian habitats for Murray Cod in each Spatial Management Unit.	Moderate
1.7	Determine the structure (age, size, spatial connectivity), dynamics, movement, dispersal and migration levels of Murray Cod populations in and between each Spatial Management Unit.	Moderate
1.9	Investigate the current reproductive status, age/size fecundity relationships, age at first reproduction, recruitment levels and longevity of key populations of Murray Cod.	Moderate
1.10	Model the significance of larger size classes to recruitment and sustainability of Murray Cod populations, and develop management strategies to achieve sustainability where skewed population structure is unsustainable.	Moderate
1.11	Identify key recruitment areas in each Spatial Management Unit.	Moderate
2.1	Determine the influence of flows on critical life history components, especially recruitment of larvae and juveniles and movement.	Moderate
2.2	Identify and model flow regulation practices (timing of releases, volumes, rate of rise and fall etc) to maximise recruitment to rehabilitate and sustain Murray Cod populations.	Moderate (DD*)
2.3	Monitor population responses to prescribed flows and incorporate this knowledge into improved flow management practices.	Moderate (DD*)
2.4	Develop and implement flow management practices to benefit recovery of Murray Cod populations.	Hard
3.2	Assess the availability and condition of riparian and instream habitat in each Murray Cod Spatial Management Unit, identify key areas for rehabilitation (e.g. fencing riparian habitat, resnagging and integrate this information into relevant river health strategies or other strategies.	Moderate
3.3	Identify barriers to movement of Murray Cod populations, particularly downstream.	Moderate
3.8	Determine, plan and implement a pilot site for remedial actions for cold water pollution for Murray Cod.	Moderate
3.16	Quantify the impact of loss of Murray Cod to water abstraction, and improve irrigation practices to reduce loss.	Moderate
3.17	Investigate the feasibility, design and implementation of potential additional Murray Cod sustainable recovery management options.	Moderate
3.18	Establish a site to trial revised Murray Cod sustainable recovery management options, identified as necessary in Action 3.17.	Moderate
3.21	Establish a whole of government responsibility which defines agency roles, responsibilities and accountability for protecting Murray Cod populations in each jurisdiction.	Moderate
3.22	Encourage uptake of responsibilities and accountabilities for protecting Murray Cod populations and their habitats both within and between agencies and jurisdictions.	Moderate
4.1	Determine the habitat use by different life stages and populations of Murray Cod and identify key habitat conditions (including water quality) to focus management actions.	Moderate

Action Number	Action Title	Ease
4.2	Survey and map potential habitat, using ecological and bioclimatic information that may indicate the location of important habitat areas.	Moderate
4.4	Develop and implement management options to protect structural habitats in floodplain channels.	Moderate
4.5	Identify and protect critical habitat areas for Murray Cod.	Moderate
4.6	Develop contingency plans for issues critical to Murray Cod populations that may occur due to unusual circumstances (e.g. drought refuges, poor water quality, isolated pools, block banks etc).	Moderate
5.1	Determine the total annual harvest (including catch and release, unknown, unreported and illegal catch etc) of Murray Cod across the Basin, and within Spatial Management Units.	Moderate
5.4	Review all compliance activities for Murray Cod across the MDB (including level and adequacy of enforcement, information provided regarding extent of illegal fishing/poaching and compliance of sale of fish) and modify as necessary to ensure Murray Cod is a priority management species to reflect the species' threatened status.	Moderate
5.7	Investigate the impact of stocking hatchery-bred Murray Cod on wild populations.	Moderate
5.10	Ensure that Murray Cod being stocked into the wild, especially where wild populations already exist, are genetically and ecologically appropriate to the location.	Moderate
5.11	Implement the quality assurance measures for hatcheries outlined in 'Managing Fish Translocation and Stocking in the MDB' workshop (WWF 2003).	Moderate
6.2	Document the significance of Murray Cod to the community, especially in Indigenous culture and oral history, and for contemporary rural communities.	Moderate
6.4	Ensure the involvement of community groups (including anglers) in the management of Murray Cod.	Moderate
7.2	Develop interim targets for each Spatial Management Unit to measure progress towards the aspirational goal towards recovery at the end of the first five years.	Moderate
7.4	Compile and transfer new knowledge and research results into an appropriate form for use by management agencies to develop management practices.	Moderate
7.5	Coordinate communication and exchange of information appropriate to the recovery program at National, State and regional levels.	Moderate
7.6	Ensure integration of Murray Cod recovery with major natural resource management programs and policies in the Basin.	Moderate
Hard		
1.8	Investigate the role and relationships of Murray Cod within the fish community.	Hard
3.4	Facilitate fish passage for Murray Cod both in upstream and downstream directions.	Hard

DD* - Data dependent

Appendix 4c: Summary of Recovery Actions by Timeframe

Action Number	Action Title	Timeframe
Short-term		
1.1	Review and synthesize published information on the population structure, status and dynamics of Murray Cod populations across the Basin.	Short-term
1.13	Develop appropriate decision support tools and models that allow the future management actions for Murray Cod to be evaluated within a risk management framework.	Short-term (ongoing)
2.2	Identify and model flow regulation practices (timing of releases, volumes, rate of rise and fall etc) to maximise recruitment to rehabilitate and sustain Murray Cod populations.	Short-term (data dependent)
3.1	Test the effects if habitat manipulations such as moving snags on Murray Cod.	Short-term
3.6	Quantify the impacts of cold water pollution on Murray Cod populations in each Spatial Management Unit.	Short-term
3.7	Develop a detailed plan for the amelioration of cold water pollution for Murray Cod throughout the MDC and ensure that existing infrastructure is used correctly.	Short-term
3.10	Investigate the incidence, severity, causes of, and responses to fish kills involving Murray Cod.	Short-term
3.11	Determine the status of Murray Cod populations in areas affected by fish kills and develop management responses for short-term protection and population recovery.	Short-term
3.12	Establish a fish kills database and website to provide information on fish kills.	Short-term
3.13	Develop and implement consistent fish kill response protocols across the MDB and ensure appropriate linkages between agencies and knowledge sharing.	Short-term
3.17	Investigate the feasibility, design and implementation of potential additional Murray Cod sustainable recovery management options.	Short-term
3.18	Establish a site to trial revised Murray Cod sustainable recovery management options, identified as necessary in Action 3.17.	Short-term
3.19	Determine the role and need for conservation stocking and/or translocation to restore or enhance identifiable local Murray Cod populations.	Short-term
3.20	Develop and apply a population model for Murray Cod to assess impacts of threats and recovery options.	Short-term
3.21	Establish a whole of government responsibility which defines agency roles, responsibilities and accountability for protecting Murray Cod populations in each jurisdiction.	Short-term
3.22	Encourage uptake of responsibilities and accountabilities for protecting Murray Cod populations and their habitats both within and between agencies and jurisdictions.	Short-term
4.2	Survey and map potential habitat, using ecological and bioclimatic information that may indicate the location of important habitat areas.	Short-term

Action Number	Action Title	Timeframe
4.3	Develop and implement protocols for rehabilitation of Murray Cod habitat and identify areas for rehabilitation to facilitate the expansion of Murray Cod populations into areas formerly occupied.	Short-term
4.4	Develop and implement management options to protect structural habitats in floodplain channels.	Short-term
5.3	Review the use and impacts of set-lines as a capture method for Murray Cod and modify regulations where necessary.	Short-term
5.4	Review all compliance activities for Murray Cod across the MDB (including level and adequacy of enforcement, information provided regarding extent of illegal fishing/poaching and compliance of sale of fish) and modify as necessary to ensure Murray Cod is a priority management species to reflect the species' threatened status.	Short-term
5.5	Provide information to politicians, magistrates and the public on the community and conservation value of Murray Cod.	Short-term
5.8	Clarify the existing uptake of low-impact practices by recreational fishers, and determine how to promote these ideals more broadly among anglers and the wider community.	Short-term
5.10	Ensure that Murray Cod being stocked into the wild, especially where wild populations already exist, are genetically and ecologically appropriate to the location.	Short-term
5.11	Implement the quality assurance measures for hatcheries outlined in 'Managing Fish Translocation and Stocking in the MDB' workshop (WWF 2003).	Short-term
6.3	Assess the level of public recognition, understanding and 'ownership' of Murray Cod, its ecology and the threats and management approaches to secure the long-term future of the species.	Short-term
7.2	Develop interim targets for each Spatial Management Unit to measure progress towards the aspirational goal towards recovery at the end of the first five years	Short term
7.3	Engage with all appropriate management agencies at an early stage in the recovery process to ensure that required management actions to protect and enhance cod populations will be implemented in a timely manner.	Short-term
7.9	Undertake a formal review and evaluation at the termination of this Recovery Plan.	Short-term
Medium-term		
1.3	Determine the genetic composition of Murray Cod populations throughout the Basin.	Medium-term
1.4	Identify appropriate Spatial Management Units for Murray Cod management (jurisdictional, habitat zones, genetic Evolutionary Significant Management Units) across their range.	Medium-term
1.10	Model the significance of larger size classes to recruitment and sustainability of Murray Cod populations, and develop management strategies to achieve sustainability where skewed population structure is unsustainable.	Medium-term
1.11	Identify key recruitment areas in each Spatial Management Unit.	Medium-term

Action Number	Action Title	Timeframe
3.2	Assess the availability and condition of riparian and instream habitat in each Murray Cod Spatial Management Unit, identify key areas for rehabilitation (e.g. fencing riparian habitat, resnagging and integrate this information into relevant river health strategies or other strategies.	Medium-term
3.3	Identify barriers to movement of Murray Cod populations, particularly downstream.	Medium-term
3.9	Develop and implement a monitoring program to assess the response of Murray Cod to remedial actions for cold water pollution.	Medium-term
3.16	Quantify the impact of loss of Murray Cod to water abstraction, and improve irrigation practices to reduce loss.	Medium-term
4.5	Identify and protect critical habitat areas for Murray Cod.	Medium-term
4.6	Develop contingency plans for issues critical to Murray Cod populations that may occur due to unusual circumstances (e.g. drought refuges, poor water quality, isolated pools, block banks etc).	Medium-term
5.1	Determine the total annual harvest (including catch and release, unknown, unreported and illegal catch etc) of Murray Cod across the Basin, and within Spatial Management Units.	Medium-term (ongoing)
5.2	Review existing and potential fishing regulations and modify where appropriate to ensure sustainable Murray Cod fisheries.	Medium-term (ongoing)
5.7	Investigate the impact of stocking hatchery-bred Murray Cod on wild populations.	Medium-term
5.9	Investigate damage and mortality rates of angler captured and released Murray Cod.	Medium-term
6.1	Promote Murray Cod as an icon species to raise awareness of river health and sustainability in the community.	Medium-term
6.4	Ensure the involvement of community groups (including anglers) in the management of Murray Cod.	Medium-term (ongoing)
7.4	Compile and transfer new knowledge and research results into an appropriate form for use by management agencies to develop management practices.	Medium-term
Long-term		
1.2	Identify gaps in distribution and population data and develop and implement a survey program to obtain data to address this.	Long-term (immediate start)
1.5	Prioritise the Spatial Management Units that require urgent or specific management actions: monitor and maintain these units.	Long-term
1.6	Identify, protect and repair key aquatic and riparian habitats for Murray Cod in each Spatial Management Unit.	Long-term
1.7	Determine the structure (age, size, spatial connectivity), dynamics, movement, dispersal and migration levels of Murray Cod populations in and between each Spatial Management Unit.	Long-term
1.8	Investigate the role and relationships of Murray Cod within the fish community.	Long-term

Action Number	Action Title	Timeframe
1.9	Investigate the current reproductive status, age/size fecundity relationships, age at first reproduction, recruitment levels and longevity of key populations of Murray Cod.	Long-term (immediate start)
1.12	Identify and quantify the environmental parameters that drive recruitment and population growth, especially age-specific survivorships.	Long-term
1.14	Develop and implement an integrated, long-term monitoring program for assessing the recovery of Murray Cod populations in each Spatial Management Unit.	Long-term
2.1	Determine the influence of flows on critical life history components, especially recruitment of larvae and juveniles and movement.	Long-term
2.4	Develop and implement flow management practices to benefit recovery of Murray Cod populations.	Long-term
3.4	Facilitate fish passage for Murray Cod both in upstream and downstream directions.	Long-term
3.5	Monitor the response of Murray Cod populations to improved fish passage.	Long-term
3.8	Determine, plan and implement a pilot site for remedial actions for cold water pollution for Murray Cod.	Long-term
4.1	Determine the habitat use by different life stages and populations of Murray Cod and identify key habitat conditions (including water quality) to focus management actions.	Long-term
5.6	Determine the contribution of stocking programs to Murray Cod populations and fishing catch.	Long-term
6.2	Document the significance of Murray Cod to the community, especially in Indigenous culture and oral history, and for contemporary rural communities.	Long-term
7.1	Establish a long-term structure for the implementation of the Murray Cod Recovery Plan through the employment of a national Murray Cod Recovery Plan Coordinator, with involvement of the Recovery Team and the Murray Cod Taskforce.	Long-term
7.7	Ensure funding submissions are organized through appropriate management agencies each year (or as required).	Long-term
Ongoing		
2.3	Monitor population responses to prescribed flows and incorporate this knowledge into improved flow management practices.	Ongoing
3.14	Ensure that opportunities are taken to collect scientific data from fish kills.	Ongoing
3.15	Identify areas and conditions of high risk of poor water quality to Murray Cod populations and develop and implement an early warning system where changes to water quality may pose a threat.	Ongoing
6.5	Ensure the results of research and management on Murray Cod are publicized through a variety of mediums such as scientific meetings, journal publications and articles for popular press, including fishing magazines and websites, and interactions with peak bodies and agencies.	Ongoing
7.5	Coordinate communication and exchange of information appropriate to the recovery program at National, State and regional levels.	Ongoing

Action Number	Action Title	Timeframe
7.6	Ensure integration of Murray Cod recovery with major natural resource management programs and policies in the Basin	Ongoing

Appendix 5: Legislation

Some State legislation includes provision for the listing and management of threatening processes relevant to aquatic and riparian habitats and thereby Murray Cod. Those listed in Victoria and NSW are summarized below. No threatening processes are listed under ACT, Qld or SA legislation.

Threatening Process#	**Listed under Legislation**	**Action Statement***
Alteration to the natural flow regimes of rivers and streams.	FFG Act (Vic)	Vic
Alteration to the natural temperature regimes of rivers and streams.	FFG Act (Vic)	Vic
Degradation of native riparian vegetation along rivers and streams.#	FFG Act (Vic), FMA (NSW)	Vic
Increase in sediment input into Victorian rivers and streams due to human activities	FFG Act (Vic)	Vic
Introduction of live fish into waters outside their natural range within a river catchment after 1770. #	FFG Act (Vic), FMA (NSW)	Vic
Prevention of passage of aquatic biota as a result of the presence of instream structures.	FFG Act (Vic)	Vic
Removal of wood debris from streams.#	FFG Act (Vic), FMA (NSW)	
Input of toxic substances into Victorian rivers and streams.	FFG Act (Vic)	
Hook and line fishing in areas important for the survival of threatened fish species	FMA (NSW)	
The installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams	FMA (NSW)	

Title of threatening process varies slightly between different legislation

*Action Statement – or similar management document in relevant State.

FFG – *Flora and Fauna Guarantee Act* 1988, FMA - *Fisheries Management Act* 1994

Appendix 6: Register of Critical Habitat (EPBC Act)

The Commonwealth Environment Minister may identify and list habitat critical to the survival of a listed threatened species or ecological community. Details of this identified habitat will be recorded in a Register of Critical Habitat.

A description of habitat listed in the Register must include enough information to identify the habitat, including its location and extent; and the reasons the habitat was identified as Critical Habitat.

It should be noted that habitat critical to the survival of a species or ecological community will depend largely on the particular requirements of the threatened species or ecological community concerned. For example, areas only incidentally used by a threatened species, and which the species is unlikely to be dependent upon for its survival or recovery, may not be areas of habitat critical to the survival of that particular species.

The Minister must, when making or adopting a recovery plan, consider whether to list habitat that is identified in the recovery plan as being critical to the survival of the species or ecological community for which the recovery plan is made or adopted. There is no legal provision for public nomination of Critical Habitat.

The Minister may, in identifying Critical Habitat, take into account the following matters:

a. Whether the habitat is used during periods of stress (e.g. flood, drought, fire);

b. Whether the habitat is used to meet essential life cycle requirements (e.g. foraging, breeding, nesting, roosting, social behaviour patterns or seed dispersal processes);

c. The extent to which the habitat is used by important populations;

d. Whether the habitat is necessary to maintain genetic diversity and long-term evolutionary development;

e. Whether the habitat is necessary for use as corridors to allow the species to move freely between sites used to meet essential life cycle requirements;

f. Whether the habitat is necessary to ensure the long-term future of the species or ecological community through reintroduction or re-colonisation;

g. Any other way in which habitat may be critical to the survival of a listed threatened species or a listed threatened ecological community.

Information on the Register of Critical Habitat is publicly available unless the Minister believes it is necessary to keep the information confidential to protect the species, community or the habitat, and/or to protect the interests of relevant landholders.

Under the EPBC Act, it is an offence for a person to take an action that the person knows will significantly damage the Critical Habitat of a listed threatened species (except a species in the conservation dependent category), or a listed threatened ecological community, if the Critical Habitat is in a Commonwealth area. Damaging Critical Habitat in a Commonwealth area is punishable by a fine of up to $110,000 or imprisonment for up to two years, or both.

If a Commonwealth agency wants to sell land that contains identified Critical Habitat, the agency must ensure that the sale contract includes a covenant to protect the Critical Habitat.

Appendix 7. Organisations with an interest in Murray Cod conservation

Organisation	Type
National/Regional	
Agriculture, Fisheries and Forestry	Australian Government
Australian Conservation Foundation	Conservation Organisation
Department of Sustainability, Environment, Water, Population and Communities	Australian Government
Field and Game Federation of Australia	Community Group
Murray-Darling Basin Commission (Native Fish Strategy, Living Murray and River Murray Water)	Inter jurisdictional agency
Native Fish Australia	Community Group
World Wide Fund For Nature	Conservation Organisation
Wetland Care Australia	Conservation Organisation
Queensland	
Department of Primary Industries and Fisheries	State Government
Department of Natural Resources and Water	State Government
Department of Environment and Resource Management	State Government
SunWater	State Government
Condamine Alliance Inc.	Regional Authority
Queensland Murray-Darling Committee Inc	Regional Authority
South West Natural Resource Management Group Inc	Regional Authority
Freshwater Fishing and Stocking Association of Qld	Fishing Organisation
Australia New Guinea Fishes Association – Qld	Community Group
Queensland Conservation Council	Community Organisation
SunFish	Community Organisation
New South Wales	
Department of Primary Industries (Fisheries Management)	State Government
Department of Environment and Climate Change	State Government
Department of Natural Resources	State Government
Department of Aboriginal Affairs	State Government
Department of State and Regional Development	State Government
Department of Local Government	State Government
Local Government Association of NSW	State Government
Shires Association of NSW	State Government
NSW Maritime Authority	State Government
State Water Corporation	State Government
Australian Museum	State Government
Murray Catchment Management Authority	Regional Authority
Murrumbidgee Catchment Management Authority	Regional Authority
Lachlan Catchment Management Authority	Regional Authority

Central West Catchment Management Authority	Regional Authority
Namoi Catchment Management Authority	Regional Authority
Border Rivers/Gwydir Catchment Management Authority	Regional Authority
Western Catchment Management Authority	Regional Authority
Lower Murray/Darling Catchment Management Authority	Regional Authority
South West Anglers Association	Angler Organisation
NSW Council of Freshwater Anglers	Fishing Organisation
Redfish	Fishing Organisation
Australia New Guinea Fishes Association - NSW	Community Group
Inland Rivers Network	Conservation Organisation
World Wide Fund for Nature	Conservation Organisation
Total Environment Centre	Conservation Organisation
NSW Murray Wetlands Working Group	Community Organisation
Murray Valley Community Action Group	Community Organisation
Coast and Wetlands Society Inc	Community Organisation
Community Environment Network Inc	Community Organisation
Nature Conservation Council	Conservation Organisation
Humane Society International	Conservation Organisation
Australian Capital Territory	
Environment ACT	Territory Government
National Capital Authority	Australian Government Authority
Upper Murrumbidgee Catchment Coordinating Committee (UMCCC)	Regional Authority
Victoria	
Department of Sustainability and Environment	State Government
Department of Primary Industries	State Government
Environment Protection Authority	State Government
Parks Victoria	State Government
Fisheries Co-Management Council	State Government
Goulburn-Broken Catchment Management Authority	Regional Authority
Mallee Catchment Management Authority	Regional Authority
North East Catchment Management Authority	Regional Authority
North Central Catchment Management Authority	Regional Authority
Goulburn-Murray Water	Regional Authority
VRFish (Victorian Recreational Fishing peak body)	Fishing Organisation
Native Fish Australia	Community Group
Environment Victoria	Conservation Organisation
Victorian National Parks Association	Conservation Organisation
Australia New Guinea Fishes Association – Vic	Community Group
South Australia	
Department for Environment and Natural Resources (SA)	State Government

Department of Primary Industries and Resources South Australia – Fisheries Division	State Government
Department of Primary Industries and Resources South Australia – Aquaculture Division	State Government
Department of Water, Land and Biodiversity Conservation	State Government
South Australian Research and Development Institute	State Government
South Australian Recreational Fishing Advisory Council (SARFAC)	Industry Group
Southern Fishermen's Association	Industry Group
Lakes and Coorong Fishers	Industry Group
River Murray Local Action Planning Groups	Community Groups
South Australia Murray-Darling Basin Natural Resource Management Board	Regional Authority
South Australia Field and Game Association	Community Group
Native Fish Australia	Community Group
Australia New Guinea Fishes Association – SA	Community Group