

National Recovery Plan for the Murray Cod *Maccullochella peelii peelii*

National Murray Cod Recovery Team



Australian Government



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Summary

Murray Cod is one of the largest purely freshwater fish in the world. It is an icon species within the Murray-Darling Basin (MDB) and has significant economic, cultural, recreational and environmental values for Australians. Murray Cod is one of four taxa within the endemic percichthyid genus *Maccullochella*. The species, which is a top order aquatic predator, has suffered a substantial decline in abundance since European settlement, particularly in the last 70 years. Many factors have contributed to this decline including localised and broad-scale impacts. Reasons for the species' decline include habitat loss and degradation, barriers to fish passage, flow regulation, cold water releases and fishing (legal and illegal). The decline of Murray Cod has mirrored a decline in environmental conditions across the MDB. The listing of Murray Cod as Vulnerable under the *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC) provides an impetus for management authorities and the broader community to take responsibility for this decline and implement immediate and long-term recovery actions.

This Recovery Plan is the first national plan prepared for this species. The long-term objective of recovery is to have self-sustaining populations managed for conservation, fishing and culture. An 'aspirational' target of restoring Murray Cod or populations to 60% of pre-European levels after 50 years of implementation has been set for the species to align it with the objectives of the Murray-Darling Basin Commission's Native Fish Strategy. Seven specific objectives have been identified which are addressed by a total of 51 priority actions and 20 other actions. The range of actions address current knowledge gaps concerning population ecology and habitat requirements, improved management of riparian and instream environments, and sustainable management of recreational fishing for Murray Cod. Effective communication, engagement and liaison between the range of national, State and regional management agencies, the Aboriginal community and interest groups including recreational anglers and conservation groups is essential for the successful implementation of the recovery plan. While this recovery plan spans a period of five years, it is expected that a timeframe of 10-50 years is required to make a significant difference to the recovery of this long-lived species.

The recovery of Murray Cod populations must occur in the context of a greatly changed environment, where there are competing and complex uses and pressures on aquatic and riparian environments. Given the wide distribution of the species and the need to address broad and local scale threatening processes, the use of 'Spatial Management Units' is required to facilitate effective management. Murray Cod rehabilitation needs to be undertaken at the population scale and complementary multi-jurisdictional management will be required for particular populations. This recovery plan identifies important populations that should be given priority protection and also highlights populations subject to serious threatening processes that require attention.

The MDB is currently the focus of a range of integrated catchment management initiatives and river health strategies aimed at improving its environmental condition. Broad programs such as *The Living Murray* and *The Native Fish Strategy*, as well as State and regional catchment management activities, include actions such as 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. The Murray Cod will be a potential major beneficiary of these initiatives, although the precise benefits are difficult to predict. A key objective of this Recovery Plan is determining how cod populations respond to improved environmental management, to better target subsequent management actions and maximise benefits for Murray Cod and the MDB. A cooperative approach between conservation and fisheries agencies and anglers is already underway to undertake many of the actions relevant to the Murray Cod recreational fishery that are outlined in this recovery plan.

There is some evidence of increases in some Murray Cod populations in recent years. Any increases need to be quantified in terms of location, extent and time periods, so that they can be placed in the context of the overall declines that have occurred in the past. Until the species' status has improved to the extent that it is no longer considered threatened, significant, long-term active management is required to protect and rehabilitate the species. There is a need to determine whether any recovery is widespread and sustained, and to identify the major contributing factors to ensure any recovery is continued.

While many actions for the recovery of Murray Cod integrate well with environmental programs, particular management actions targeting the species are also required. There is great potential for Murray Cod to act as an 'umbrella' species whose requirements may well encapsulate the needs of many other species in the system. There is also increasing emphasis on management of communities rather than single species, and this recovery plan acknowledges and incorporates this holistic approach.

Species' Information

Legal 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 1988. 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'.

Distribution

Natural distribution

The Murray Cod is endemic to the Murray-Darling River system in south-eastern Australia, including South Australia (SA), Victoria, New South Wales (NSW), Australian Capital Territory (ACT) 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). 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 SA, 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, pers. comm.). 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 NSW 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. Boeroopki Swamp, Green Lake, Taylors Lake) periodically dry up and local populations die out. The species has been found in the Light River in SA (M. Hammer, pers. comm.). The species was also introduced but failed to establish in Western Australia (Morrissey 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.

Within its range, the Murray Cod occurs naturally in the following IBRA (Interim Biogeographic Regionalisation in Australia) 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.

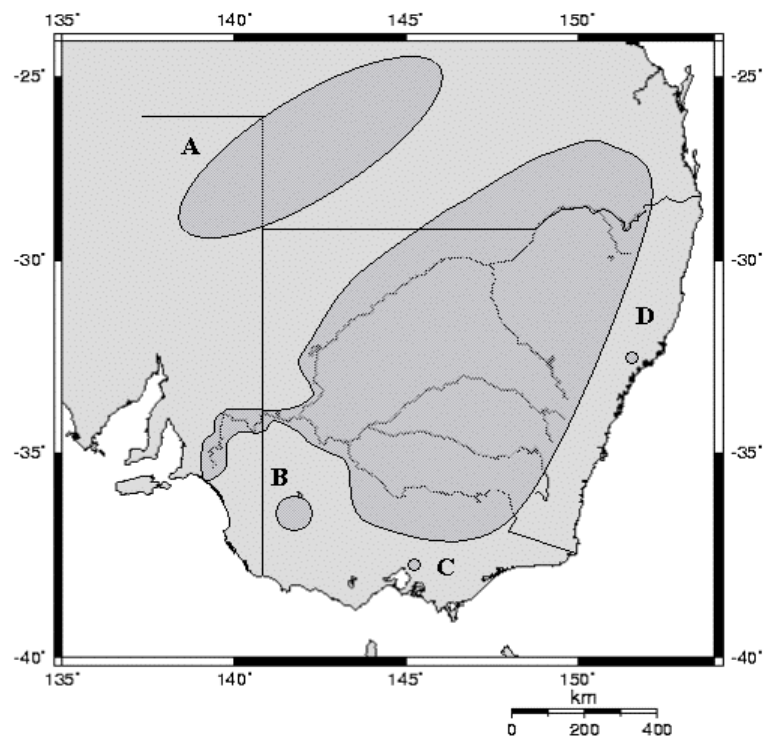


Figure 1. Distribution of the Murray Cod

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)

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).

Key Ecological Characteristics

Murray Cod is the top-order or apex aquatic predator in the Murray-Darling River system (Rowland 2005, Ebner 2006, Baumgartner 2007). At the time of European settlement, the species appeared to have been remarkably abundant, possibly reflecting the relatively simple aquatic communities and short food chains within this range. It is likely the abundant species had a profound impact on food chains and the aquatic community although its ecological significance is difficult to quantitatively assess. Kearney and Kildea (2001) suggested '*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*'.

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 woody structure, 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 aggregations may occur. As an apex predator, Murray Cod feed mainly on fish and large crustaceans (Ebner 2006, Baumgartner 2007).

Murray Cod is amongst the most long-lived Australian fish, aged up to 47 years (Anderson *et al.* 1992). A 1.27m fish collected from the Murray River in 1996 downstream of Yarrawonga was aged at 49 years (Greg Sharp, DPI, pers. comm.). An age estimate of the largest cod ever caught (113.6kg) was between 74-114 years old (Rowland 1988a). Fish generally reach sexual maturity at 4-6 years of age 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 in winter and fish probably mature later and at a larger size than fish in more northern waters (Glenn Wilson, UNE, unpublished data).

The species has an annual reproductive cycle and a short, defined, breeding season. Murray Cod form pairs and spawn in spring-summer, in response to rising water temperatures of 16.5-23.5°C, with most spawning thought to occur at around 20°C (Cadwallader and Gooley 1984; Gooley *et al.* 1995; Rowland 1985, 1998a). Murray Cod have been shown to spawn in the wild with water temperatures as low as 15°C (Humphries 2004; Koehn and Harrington 2006). Reproduction appears 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 commences in early spring in the northern areas, but may not commence until late spring or early summer in the southern areas (Rowland 1988b). 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, although it is not known if these are resting places or used for spawning. Eggs are typically deposited in a layer one-egg thick and are guarded by the male fish. Eggs hatch after 4-13 days, depending on temperature (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 spawning and spawning of male fish with multiple partners have been recorded (Rourke *et al.* 2009). After several days at the spawning site, larvae rise in the water column and drift with the current (Humphries *et al.* 2002; Koehn and Harrington 2005, 2006). Peak abundance occurs in November, although larvae may be present for up to 10 weeks (Koehn and Harrington 2006).

While spawning does not apparently 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 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 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).

Murray Cod have generally been considered to be sedentary. This is largely so for autumn and winter when movements are localised 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), returning to their original territory several weeks after spawning. Homing occurred for about two thirds of fish. There was variation in movement patterns between individuals, size and fish location. Larger movements were restricted to fish > 650 mm TL in river fish. Fish from Lake Mulwala moved greater distances than those in the Ovens River (Koehn 2006). Upstream movements may coincide with rising water levels, although some movement occurs without flooding. Migration does not appear essential for spawning as Murray Cod are known to spawn in impoundments (Cadwallader and Gooley 1984) and farm dams.

Population Genetics

Populations are discrete groups within a species that can potentially interbreed, but may differ in traits such as phenotype, genetics, reproduction and growth (Ryman and Utter 1987). Populations of freshwater fish are usually isolated or semi-isolated by barriers (e.g. terminal wetlands, areas of unsuitable habitat, dams, unconnected drainages) that prevent or restrict gene flow. Genetic differences between populations at neutral loci may in some cases reflect adaptation to local environmental conditions (Conover et al. 2006; Larsen et al. 2007).

Populations are a basis for fisheries management and conservation (Hallerman 2003). Identifying populations is of critical importance, particularly for threatened species, exploited species or species where hatchery-reared fingerlings are used to enhance stocks. Inappropriate stocking may adversely affect species and populations through loss of genetic diversity, loss of genetic identity, introgression and by reducing effective population size. Genetic diversity is the raw material for evolution and a loss of diversity reduces the ability of populations to adapt in response to environmental change (Frankham *et al.* 2000). Consequently, the identification of populations is an essential step in fisheries management, particularly for stock enhancement and conservation of threatened species and populations where genetic diversity and genetic integrity must be maintained.

Population genetics is a relatively new, rapidly growing, field that has revolutionised the understanding of population structure and molecular techniques are used to identify populations and determine the level of genetic diversity in a species. A recent PhD project investigated the population genetic structure of Murray cod across the Murray-Darling River system (Rourke 2007). This work has identified that there are discrete populations of Murray Cod in the Murray-Darling River system and these may form the basis of Spatial Management Units (see later section).

Important Populations

The identification of Important Populations can assist in identifying priority sites for protection and the implementation of a range of management recovery actions. This is particularly relevant to a species such as Murray Cod that occurs over a wide area where a large number of rehabilitation activities could potentially be undertaken. Prioritisation of management attention already occurs in many cases across the range of Murray Cod, where significant populations are already recognised.

The Recovery Team and Murray Cod Taskforce developed a number of criteria which could be used to identify an Important Population. These criteria incorporate consideration of genetic, ecological and management issues:

- Genetics – are there particular genetic units that need preservation?
- Scale – appropriate sized areas to support the security of genetics/population size/environmental units
- Population size/integrity/demographics/abundance – that will support recruitment/breeding stocks
- Recreational fishing based on wild populations (not stocked) - while some stocking may occur, many Murray Cod recreational fisheries are based predominantly on natural populations.
- Regional importance – geographic representation (upland, lowland)
- Cultural (Aboriginal) importance
- Scientific importance (reference site, type locality, etc.)
- Quality of fish community

Table 1 summarises the list of Important Populations identified through this process. They are considered necessary for the long-term survival and recovery of Murray Cod, and are listed in approximate order of importance for each State. Population based recovery, rather than species-based recovery has been recommended for Murray Cod (Lintermans *et al.* 2005). This highlights the importance of population and habitat assessment, discrimination of genetic types, mapping and the determination of the appropriate Spatial Management Units for this species. In some situations there may be overlap between areas recognised as Important Populations and

Populations Under Threat (see later section). It is also possible that one population may include several Spatial Management Units (see later section).

Table 1. Location of Important Populations of Murray Cod

Location	Comments
<i>Australian Capital Territory</i>	
Murrumbidgee River	<ul style="list-style-type: none"> • Scale • Population size/integrity etc • Regional importance (near upland limit of its distribution in the Murrumbidgee) • Quality fish community
<i>New South Wales</i>	
Darling River main channel including minor tributaries and anabranches downstream on Menindee	<ul style="list-style-type: none"> • Scale • Population size/integrity etc • Regional importance • Quality fish community
Murray River main channel including minor tributaries and anabranches, downstream, of Yarrawonga	<ul style="list-style-type: none"> • Scale • Population size/integrity etc • Regional importance • Quality fish community
Murrumbidgee River from Wagga to Hay	<ul style="list-style-type: none"> • Scale • Population size/integrity etc • Regional importance • Quality fish community
Edward River including most major tributaries	<ul style="list-style-type: none"> • Scale • Population size/integrity etc • Regional importance • Quality fish community
Namoi River from Peel River junction downstream to Wee Waa, including most major tributaries except upper Mooki River	<ul style="list-style-type: none"> • Population size/integrity etc • Regional importance • Quality fish community • Formerly a genetically distinct population
Gwydir River including major tributaries from Copeton Dam to Gwydir River	<ul style="list-style-type: none"> • Population size/integrity etc • Regional importance • Quality fish community • Formerly a genetically distinct population
Border rivers (Barwon and Macintyre) including all major tributaries in NSW	<ul style="list-style-type: none"> • Population size/integrity etc • Regional importance • Quality fish community
<i>Queensland</i>	
Border Rivers	<ul style="list-style-type: none"> • Regional importance (representative upland population) • Some evidence that there was once a genetically distinct population in the Macintyre and Bearded Rivers
Condamine River – upland reaches	<ul style="list-style-type: none"> • Largely intact fish community • Low impact from noxious fish species • Evidence of natural recruitment
Warrego River between Charleville and Cunnamulla	<ul style="list-style-type: none"> • Good population structure
McIntyre River downstream of Texas	<ul style="list-style-type: none"> • Good population structure
<i>South Australia</i>	
lower Murray River (floodplain and gorge reaches)	<ul style="list-style-type: none"> • Population structure dominated by large fish (>700mm), limited recruitment since 2000 • Rec fishing, purely based on wild population • Aboriginal culture, education for local community • Educationally important lower Murray fish community
Chowilla anabranch system	<ul style="list-style-type: none"> • Unique habitat in SA (flowing waters and dense large woody structure) • Good population structure • High abundances of reproductively mature fish

Location	Comments
Lakes Alexandrina and Albert	<ul style="list-style-type: none"> Historically only an important part of the commercial fishery during drought years. May provide a refuge
Victoria	
Mullaroo/Lindsay/Wallpolla	<ul style="list-style-type: none"> Important largely wild population of large, spawning fish, natural flows
Ovens River	<ul style="list-style-type: none"> Unregulated river – scientific site Wild population (may have had early history of stocking), relatively natural flows, linked to NSW most important population, Lake Mulwala and the King and Murray River main channel up to Hume Dam
Ulupna Creek	<ul style="list-style-type: none"> Fish interact with the mainstem of the Murray River
Goulburn River (downstream of Lake Nagambie)	<ul style="list-style-type: none"> Subject of fish kill, illegal fishing Some recent resurgence of numbers but also a recent reduction in numbers of legal size fish History of stocking
Kiewa River, lower reaches	<ul style="list-style-type: none"> Fish regularly caught, recent stocking Large sand deposits limit movement especially in low flows Linked to the Murray River main channel between Hume Dam and Lake Mulwala
Broken Creek	<ul style="list-style-type: none"> Barriers, subject to fish kill, recovery, long history of stocking
Broken River (downstream of Nathalia), in lower river, d/s of Rices Weir	<ul style="list-style-type: none"> Scientific site, smaller river, stocking, fish kill in 2002 Population u/s of Rices Weir fragmented and history of stocking
King River, lower reaches	<ul style="list-style-type: none"> Small population near the altitudinal edge of its range, interacts with Ovens River

Decline

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, especially in the last 70 years (Cadwallader and Gooley 1984; Harris and Gehrke 1997; Rowland 2005), and some recent localised extinctions have occurred (Koehn *et al.* 1995). 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 km², within which there has been substantial loss and degradation of habitat (TSSC 2001). While there are still some good local populations, at a national scale the Murray Cod has declined, populations are fragmented and the species is currently listed as Vulnerable. A review of the status of Murray Cod in 2001 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).

In Victoria, the species has undergone a marked 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 in 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 the construction of the dam because of cold water pollution (Koehn *et al.* 1995). The Broken Creek population was subject to a major fish kill in February 2002 (Koehn 2005a) and recovery has been limited. Recent fish kills have impacted several populations in the Ovens River and Goulburn-Broken River systems (Koehn 2005a).

In NSW, 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). A 1996 survey did not record any Murray Cod at 20 randomly selected sites on the Murray River, and recorded the species 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). While Murray Cod remain relatively common in many areas of NSW, there is concern about altered and possibly unstable population structure. In the Murray River between Tocumwal and Yarrawonga, a heavily fished area where cod are locally common, the population is heavily skewed to small, pre-breeding size fish (<50 cm length). Fish in the 50–90 cm size range (prime breeding range) are much fewer in number than would be expected to occur in a natural population, leading to the possibility of an unsustainable population structure (Nicol *et al.* 2005).

Murray Cod remain distributed throughout their historical range in SA and Qld. No cod have 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 the 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 Zampatti 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.

Possible Indications of Recovery

While Murray Cod populations as a whole have declined throughout the MDB, and some populations are highly threatened, there is evidence of some recovery in some areas. For example, many anglers have reported improved catches in particular areas and there are reports in fishing magazines and the media concerning improvements in Murray Cod fishing. It is essential that the extent of any population increases is quantified so that it can be placed in the context of the overall declines of the species which have occurred in the past. This information may be obtained from standardised surveys that give information across the population structure as well as quantified observations of anglers. Actions within the recovery plan address this gap in quantifiable data e.g. actions under Objective 1 (determine the distribution, structure and dynamics of populations) while action 5.1 addresses recreational angling data. The determination of the total annual harvest of Murray Cod (including catch and release, unknown, unreported and illegal catch), would greatly assist in the ability to quantify changes in population levels.

Reasons for any population increases also 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 as recognised by its EPBC listing, active management is required to protect and rehabilitate the species. A key challenge is to determine whether any recovery is across the board and sustained, and to identify the major contributing factors to ensure such recovery continues. Gaining an understanding of reasons for improvements in the species' status in particular areas will also enable appropriate focus on implementing key rehabilitation activities. Investigating the environmental parameters that influence the recruitment and survival of Murray Cod will also greatly assist in understanding the reasons for recovery. The recovery plan includes a range of actions that address this through research and adaptive management approaches.

Current Assessment of Population Status

Assessments of current population status are provided below for each of the States and Territories where Murray Cod occurs. These are based on an interpretation of the results of relevant survey data and also include the opinions and observations of angling groups.

ACT

In the ACT Murray cod is managed as a significant component of the freshwater fishery. Most populations in the ACT are put and take fisheries in urban lakes such as Lake Burley Griffin, Lake Ginninderra, Lake Tuggeranong, Gungahlin Pond, Yerrabi Pond and Googong Reservoir in adjacent NSW (fishery jointly managed with NSW DPI). Fish are stocked into these water bodies on a regular basis (Lintermans 2003), and provide valued recreational fishing opportunities as well as relieving the pressure on wild riverine populations. Urban lake fisheries are regularly monitored under a standardised scientific assessment program that has been in place since the 1980s (Lintermans 2000). However, returns of Murray cod in the monitoring program are low, as the sampling technique (gill nets) are not particularly well suited to a sit and wait predator like cod. Regular angler reports of good cod being caught in urban lakes are the major information source on the status of cod populations in these water bodies.

Riverine cod populations are largely confined to the Murrumbidgee River in the ACT, as impoundments, poor habitat and historic fish declines (Captains Flat mine pollution) have significantly depleted stocks in other rivers such as the Molonglo and Gudgenby. The ACT has a biennial standardised fish monitoring program from the Murrumbidgee River, but it suffers from the same gear selectivity issues as the urban lakes monitoring program. There is no monitoring of larval cod abundance or distribution in the ACT.

Ad-hoc creel surveys and angler reports continue to provide evidence of reasonable cod numbers and size structure in the Murrumbidgee River.

New South Wales

In NSW, Murray Cod is managed as a major component of the freshwater fishery. There are no broad scale and ongoing monitoring programs directed specifically at Murray Cod. However data is available from programs such as the Sustainable Rivers Audit (SRA), Integrated Monitoring of Environmental Flows (IMEF) and the NSW Threatened Fish Monitoring Program. A number of localised monitoring programs such as those targeting fish movements through fishways and responses to river rehabilitation works also provide incidental data on Murray Cod. Further data is obtained via the Recreational Fishing Tournament Assessment Project and anecdotal reports from angling groups.

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.

Murray Cod are stocked annually into a range of impoundments and streams in order to enhance the recreational fishery. All stocking activities are required to comply with the NSW Freshwater Fish Stocking Fishery Management Strategy (NSW DPI 2005) which includes consideration of issues such as genetic management, biosecurity, impact on other species including threatened species, natural range, fish welfare and angler demand.

Queensland

There are no Basin-wide ongoing monitoring programs for Murray Cod in Queensland. Data are available from programs such as the DPI&F Long-Term Monitoring Program and the Sustainable Rivers Audit. These surveys, however, examine the entire fish community and are not designed to describe the structure of cod populations. Available information is drawn largely from discrete research projects and anecdotal reports provided by the local angling community. Extensive fish stocking in the MDB is in some cases making it difficult to assess whether fish are recruiting naturally, thus masking the true status of remaining populations. Cod are locally abundant in a number of areas and there is evidence of natural recruitment in some areas

where limited stocking has occurred. This is particularly evident in sections of the Warrego and McIntyre rivers.

South Australia

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 700mm 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.

Anglers have however consistently reported a resurgence of catches of Murray Cod in various year classes in the South Australian section of the Murray River including Chowilla (Peter Teakle, pers. comm.). There have been many anecdotal reports from anglers of Murray Cod caught in South Australian waters of undersize to 10-15kg and greater (Peter Teakle, pers. comm.).

Victoria

There is no overall Murray Cod population monitoring program within Victoria. However, there appears to be little evidence for similar 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-ARI 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, DSE-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, DSE-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). 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.).

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.

Anglers, however, have consistently reported a resurgence of catches of Murray Cod in most year classes in the Murray River and its tributaries including Victorian riverine systems with many reporting the best Murray Cod fishing in decades (Rob Loats, VRFish, pers. comm.).

Threats

The threats to Murray Cod have been summarised in several recent publications (Koehn 2005b; Lintermans *et al.* 2005; Rowland 2005; TSSC 2001) and so are only discussed briefly in this recovery plan. 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. Environmental changes are probably the main cause of the substantial decline in abundance of Murray Cod. The species' decline in NSW may have had different causes at different stages (Rowland 2005).

Murray Cod has been and continues to be impacted by a range of threats to its habitat. 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. Some threats such as fires and deteriorating water quality causing fish kills are erratic and episodic. The cumulative impact of many small or low risk threats (e.g. fish kills, angling mortality, 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 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 such a species, localised extinctions may continue to occur after the primary cause of decline has ceased.

The major current and suspected threats impacting on Murray Cod are detailed as follows:

Flow Regulation

Many rivers in the MDB 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, and changes include 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 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.

River regulation and altered flow regimes is implicated in the decline of many Murray-Darling River system fish species (MDBC 2004a) and 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). 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 cause changes in suitable conditions for spawning and larval recruitment of Murray Cod (Rowland 1989). Reduced flows affect the ability of fish to migrate, especially those species that undertake pre- or post spawning movements and also reduces the amount of habitat available. 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). While fish exclusion devices are used elsewhere in the world to avoid fish loss to irrigation systems, no exclusion devices have been fitted to irrigation offtakes despite the heavy reliance on irrigation water in the MDB (Blakeley 2005).

Habitat degradation

Habitat degradation may occur through a variety of causes. Desnagging involves the removal, lopping or realignment of 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. The removal of woody habitat has been widespread in MDB rivers, particularly in

lowland reaches over a large number of years (Gippel *et al.* 1992; Mudie 1961; Phillips 1972; Treadwell *et al.* 1999). 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. Desnagging has undoubtedly reduced or destroyed prime habitat for adult Murray Cod, and has also led to fragmentation of remaining available habitat. While desnagging now rarely occurs, 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 these activities over time are probably substantial, and the long-term effects of widespread desnagging may still be impacting Murray Cod populations. Reinstatement of woody habitat is now 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 2003 burnt through some 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 large amounts of sediment and ash into the system. The infilling of undulations and holes may also impact on cod habitats and 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. Reductions in riparian vegetation result in reduced organic inputs including woody habitat (Hynes 1970).

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. These conditions can result in fish kills, and have been recorded regularly in recent years. Suspended sediment, low oxygen levels, herbicides and altered water temperatures have all been suggested as possible causes of recent fish kills, including large numbers of Murray Cod (Koehn 2005a). These kills have probably resulted from a number of factors, exacerbated by extremely low (or no) flows, sudden releases from dams of high temperature or low dissolved oxygen water. Modelling of the impact of the Darling River fish kill on the Murray Cod population indicates that it will take decades for the cod population to recover, and will be extremely costly (Koehn 2005a).

Increased salinity in the MDB is a major problem causing extensive degradation in some areas. High turbidity and salinity may cause adverse physiological or behavioural effects on fish. Stratification may occur in pools due to temperature or salinity gradients, resulting in de-oxygenated, saline bottom layers (Anderson and Morison 1989). While adults of many native fish species have at least a short-term tolerance to moderate to high salinity levels, 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. Salinities above 0.34g/L may result in significant impacts on Murray Cod (Chotipuntu 2003). Elevated salinity levels may also affect food sources such as invertebrates, algae and macrophytes, consequently affecting habitat complexity and quality.

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). Cold-water pollution may lead to localised extinctions of native fish downstream of large dams. 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. 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).

Release of pollutants and toxins to rivers may directly poison fish. Declines and local extinctions in northern NSW in the early 1900s were linked to regular fish kills caused by agricultural chemicals (Rowland 2005). Herbicide use is widespread in the irrigation channel system in Victoria, 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). Heavy metal poisoning from the Captains Flat mines caused the local extinction of Murray Cod from the Molonglo River in the ACT (Lintermans 2002). Impacts of lesser known chemicals such as hormones from sewage effluents on fish breeding and sex ratios 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 MDB (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. Recent research indicates that Murray Cod larvae have a nocturnal downstream drifting stage and some adult cod make substantial upstream and downstream movements of several hundred kilometres (Koehn 1996; Koehn and Nicol 1998; Humphries *et al.* 2002; King 2002). Barriers may interfere with pre and post spawning movements of Murray Cod, and fragment and isolate populations from one another, which could lead to 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, including Murray Cod (Barrett and Mallen-Cooper 2006). Fishways however 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. Possible impacts on Murray Cod include through predation, competition, habitat alteration and spread of diseases and parasites. While the impact of alien species is probably substantial, in some instances it can be difficult to separate from other threatening processes.

Carp is a typical invasive species, which is resilient and well-adapted to exploiting riverine environments that are already degraded (Koehn *et al.* 2000; Koehn 2004). At high densities Carp may increase turbidity and reduce aquatic vegetation through their feeding habits, reducing habitat for native species. 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. Despite public opinion, there is no scientific evidence that increases in Carp have affected Murray Cod numbers (Koehn *et al.* 2000). There is however 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). Effects of other species that can reach very high densities, such as Eastern Gambusia and Oriental Weatherloach *Misgurnus anguillicaudatus*, are not known. Alien species are also suspected of introducing a number of parasites and diseases to Australia (see diseases section below).

Commercial Fishing

Murray Cod was once common enough to support commercial fisheries, based mainly in the Murray and Murrumbidgee rivers (Dakin and Kesteven 1938; Kailola *et al.* 1993; Kearney and Kildea 2001; Reid *et al.* 1997; Rowland 1985, 1989, 2005; Ye *et al.* 2000). 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). A smaller peak in the fishery occurred 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).

Recreational Fishing

Murray Cod is 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.). The National Recreational and Indigenous Fishing Survey estimated 106,000 cod weighing 216 tonnes were caught and retained, while another 368,000 cod were caught and released in a 12 month period from March 2000 (Park *et al.* 2005). 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). 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). The removal of 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. There is also concern that the current minimum size limit of 50 cm in all states 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 (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 in the Mullaroo Creek (Steve Saddler, DSE-ARI, pers. comm.). This information comes from verified angler returns. The numbers of other fish potentially lost through illegal take is unknown.

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 use of set-lines and other regulations for recreational angling are currently being reviewed by NSW and SA fisheries authorities.

All jurisdictions now have regulations governing cod fishing, including size and bag limits, and closed seasons (Lintermans 2005) although there is no consistent regulatory regime. 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 and future breeding success of released Murray Cod is not known. 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 SA and NSW 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.

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 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.

Stocking

Stocking of Murray Cod fingerlings from hatcheries is currently an important management tool used to supplement or create cod fisheries across the MDB, and can also aim to assist in long-term conservation of a population. These stockings are primarily for recreational fishing purposes. An estimated 1 million cod are stocked throughout the Basin each year, primarily in Victoria and NSW, mostly in impoundments rather than rivers (Lintermans *et al.* 2005), although some stocking of weirs occurs. Approximately 5 million fingerlings were stocked into NSW waters in the period of 2000 to 2007 inclusive. 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 masking 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. 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). In addition, a recent study found that several catchments in the northern MDB (Border, Gwydir and Namoi) were likely to have been genetically distinct populations prior to stocking, which resulted in introgression of stocked and wild fish (Rourke 2007). This study also showed

that fish produced for stocking by a hatchery in Victoria were less genetically diverse than wild populations (Rourke 2009). 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 and in the near future, all hatcheries in NSW will be required to comply with this program. 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.

Diseases

Very little is known about the prevalence and impact of diseases on Murray Cod. The major concern probably relates to those exotic diseases introduced to Australia with imported fish which 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 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 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 the *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 potentially likely to 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).

Populations Under Threat

All Murray Cod populations throughout the MDB have been affected to some extent by the impact of one or more threatening processes during the last 100 years, and it is fair to say that all populations still exhibit the consequences of these threats, through reduced abundance since European settlement. Most (if not all) populations are still affected by the many threats still operating at a landscape scale. Whole river systems are affected by altered flows and water removal; almost 3000 km of waterways are affected by cold water pollution; the 3600 barriers on rivers in the MDB are still affecting populations, even though some barriers now have fishways facilitating a degree of upstream movement; and fish kills are becoming an increasingly regular event in widely separated locations.

While every population is under a degree of threat, the significance of threats fall unevenly across the landscape. Some populations (e.g. in the Victorian tributaries of the Murray River) are under a much higher degree of threat than others as indicated by their heightened conservation status and the loss of large fish in fish kills in some rivers in recent years. There is also evidence that some populations in NSW are recovering (Rowland 2005). However, 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 (Table 2).

In order to assess Murray Cod populations under threat, some general criteria for population significance were derived to assist this process:

- Confirmed history of decline (population still extant)
- Identifiable threat/s (desnagging, alien species, illegal fishing, recreational fishing, thermal pollution, altered flow regimes etc.)

These criteria were then used by the Murray Cod Recovery Team and Murray Cod Taskforce to assess populations. Locations of Murray Cod populations under serious threat are given in Table 2. In some cases 'Take' is used where exploitation cannot be distinguished between legal and illegal efforts.

The identification of particular Populations Under Threat can assist in prioritisation of recovery actions at particular sites. Prioritisation of management attention already occurs in many cases across the range of Murray Cod, where significant threats to particular populations are already recognised. In some situations there is overlap between Populations Under Threat and Important Populations. Several Spatial Management Units (see later section) may also occur within a particular population. In such cases, there is even greater need to prioritise these sites for recovery actions.

Table 2. Locations of populations under serious threat.

Location	Current threats
New South Wales	
Lachlan River – entire length	River regulation (including water extraction for irrigation), poor water quality, inappropriate fish stocking (loss of unique genetic identity), low numbers of broodfish, no or low levels of recruitment, exotic fish.
Murray River 'slopes'	Low numbers of broodfish, no or low levels of recruitment, exotic fish.
Macquarie River 'lowlands'	River regulation (including water extraction for irrigation), no or low levels of recruitment, inappropriate fish stocking (loss of unique genetic identity), exotic fish, illegal fishing.
South Australia	
lower Murray River downstream from NSW border	River regulation (significant change in flow regime), low and stable summer and winter flows, desnagging, recreational fishing, illegal fishing, barriers to fish movement (upstream movement of adults/juveniles and downstream drift of larvae), sedimentation in low flow areas.

Location	Current threats
Victoria	
Avoca River	Illegal use of set-lines; salinity.
Broken Creek	Poor water quality; weirs blocking movement, although fish passage provided there are issues concerning appropriate flow through structures and limitations of downstream movement through barriers and influences on larval drift; fish kills; flow regulation.
Broken River	Poor water quality through reduced flows, weir blocking movement, fish kill, poor riparian zone and fragmented habitat, localised illegal fishing (set lines and drum nets), poor water quality.
Campaspe River	Cold water pollution; altered flows, water extraction, lack of flow to allow for connectivity of pools and provision of breeding cues; barriers to fish passage, black water events, poor riparian zone, illegal fishing
Goulburn River	Cold water pollution (downstream Lake Eildon) and poor water quality in releases from impoundments; altered flows at breeding time; herbicide use in irrigation channel system; subject of fish kill; localised illegal fishing; barriers to fish passage; removal of instream wood; spread of introduced pest species.
Gunbower/Pyramid Creek	Illegal fishing; river regulation; poor riparian zone.
Kiewa River	Take; sediment from tributaries; poor riparian zone health; illegal fishing (occasional set lines and drum nets); cold water pollution; fragmented habitat (deep pools disconnected during low flows), altered summer flows.
Little Murray River	Altered flow regimes; poor water quality; barriers to fish passage.
Loddon River	Cold water pollution; altered flows; lack of water to enable connectivity of pools and provision of breeding cues; loss of habitat through previous desnagging; poor riparian zone and grazing pressure; illegal fishing.
Mitta Mitta River	Cold water pollution, altered flow regime removing breeding cues, loss of habitat through previous desnagging and rock beaching, poor riparian zone health.
Ovens/King River system	Poor water quality through siltation; loss of habitat through previous river use and improvement programs in the upper reaches. Potential longer term loss of suitable spawning habitat due to increased fine sediment loads due to 2003 and 2006 fires. Critical Low summer flows and isolation of pools during drought. Limited localised illegal take (mainly set lines) in stream structures (at Wangaratta and Everton).
Mullaroo/Lindsay Wallpolla	Overharvesting of large, spawning fish; organised illegal commercial take and local take for consumption and sale. Potential change in flows due to expansion of irrigation industry and/or introduction of new regulators.
Cudgewa Creek	Low summer flows, siltation, fragmented habitat.
Buffalo River	Altered flow regimes (summer), siltation from fires (2003 and 2006), fragmented habitat. Ongoing sediment input infilling holes. Impacts of regulation from Lake Buffalo.

Spatial Management Units

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 for management. This Recovery Plan incorporates the concept of using 'Spatial Management Units' to facilitate implementation of recovery actions (see Figure 2). Currently the management of Murray Cod is delineated by jurisdictional boundaries with no consideration to the spatial and temporal scales that populations operate within. Consequently, the ecological, habitat and management requirements of populations may be compromised by existing management boundaries.

The distribution of Murray Cod can be divided into populations within which Spatial Management Units may occur. This provides the potential to prioritise areas for management and rehabilitation actions. If such a Spatial Management Unit is split by a jurisdictional boundary, it is important that complementary multi-jurisdictional management can take place. This will require effective communication between agencies and consistent management approaches to particular recovery actions. This is already happening to some extent in the management of particular sites.

A number of actions within this plan relate to identifying Spatial Management Units, as well as gaining an understanding of their structure, dynamics etc, as well as focusing on their rehabilitation and protection (Actions 1.4, 1.5, 1.6, 1.7, 1.11, 1.14, 3.17). Action 1.5 in particular involves prioritising Spatial Management Units requiring management action, and focuses on monitoring and maintaining these units. Other actions within this plan address the need for improved liaison and knowledge transfer between agencies to improve management responses, in particular Actions 7.3, 7.4, 7.5 and 7.6.

The use of Spatial Management Units to facilitate implementation of actions for distinct areas follows the approach in the *Native Fish Strategy for the Murray-Darling Basin 2003-2013* (MDVBC 2004a), which established the use of River Management Zones and Habitat Management Areas, which reflect the ecological functioning of rivers as well as management capabilities.

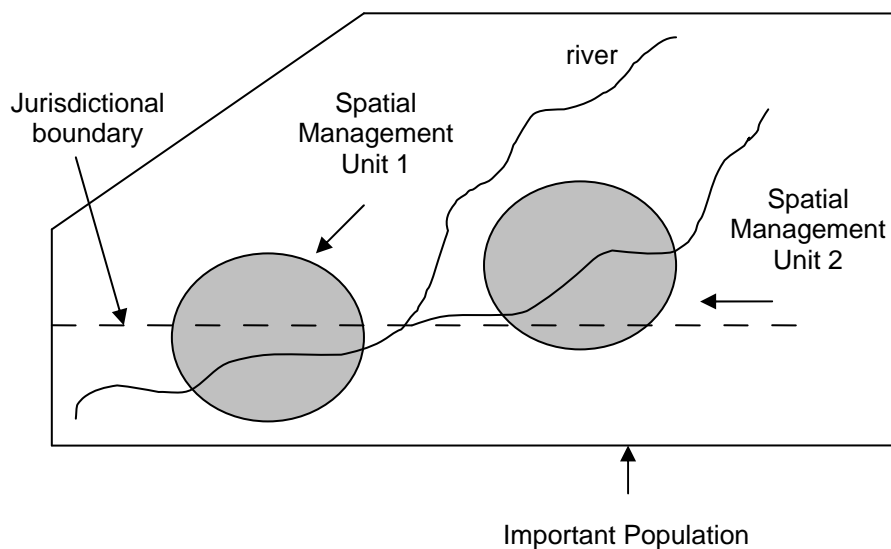


Figure 2. Jurisdictional boundaries, Important Populations and Spatial Management Units

Recovery 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 populations.

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 MDB, 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).

The recovery program for Murray Cod must also 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.

Integration with Existing Rehabilitation Programs

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.

Broad Scale Rehabilitation Programs

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 and river health strategies, 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.

State/Territory Based Programs

Australian Capital Territory

The ACT does not have any active research programs specifically directed at wild Murray Cod, although the riverine and urban lakes monitoring programs provide some information on the growth, survival and ecology of the species.

New South Wales

NSW is undertaking a number of research projects with direct or indirect benefits to Murray Cod population management. These include a study into short and long-term survival of Murray Cod following angler release leading to improving survival rates by assessing gear type and methods of handling, and contributing to a broader project (by PIRVic) to determine the sensitivity of population structure to fishing impacts (FRDC funded). More general projects include assessing fishway designs, identifying methods for mitigating impacts of water diversions, assessing stocking activities (survival, impacts on extant populations) and assessing mortality during downstream transport. NSW DPI's various freshwater fish monitoring programs also contribute data to ongoing Murray Cod stock assessment.

South Australia

There are a number of research projects within SA that incorporate Murray Cod. A Native Fish Monitoring project (PIRSA) utilises ex-commercial fishermen to collect relative abundance, size, composition and biological data for species including Murray Cod at sites throughout the River Murray in SA. The Murray River Fishways Assessment Project (MDBC) which is investigating the function and success of River Murray fishways provides ad hoc Murray Cod size composition and relative abundance data from quantitative electrofishing surveys. The Chowilla Fish Ecology Project (MDBC) is investigating various aspects of fish ecology in the Chowilla anabranch system and adjacent River Murray, including spawning, recruitment and movement of Murray Cod. The Katarapko Demonstration Reach Fish investigations (MDBC) is providing baseline fish assemblage data for the Katarapko Creek system and adjacent River Murray which provides ad hoc data on Murray cod. The Fish Habitat Assessment of the SA River Murray Main Channel project (SA MDB NRM Board) is investigating fish habitat associations in the lower River Murray and aims to develop a tool to assist conservation managers in the planning of comprehensive and representative reserve systems of freshwater protected areas. This project may provide information of Murray Cod habitat relationships.

Victoria

There is a range of projects occurring in Victoria which are investigating the ecology of fish communities, impacts of particular threatening activities and responses to rehabilitation activities. These include the recruitment of ecology of fish (King *et al.* 2007), the use of anabranches (Saddler, DSE-ARI, unpubl. data) and irrigation channels (O'Connor and King, DSE-ARI, unpubl. data) and response to resnagging (Nicol and Lyon, DSE-ARI, unpubl. data), the effects of thermal pollution in the Mitta Mitta River and in the Murray River downstream of Lake Hume (Todd *et al.* 2006, Sherman *et al.* 2007). These projects provide information on a range of fish species, including Murray Cod. There are also a number of projects occurring which specifically relate to Murray Cod, including determination of the habitat requirements and movement of Murray Cod (Koehn 2006), the assessment of survival rates of stocked fish (Crook, DSE-ARI, unpubl. data), investigations into sustainable recreational fisheries for Murray Cod (Brown, DPI, unpubl. data), and a recent modelling project to address different management scenarios for the species (Todd and Koehn, DSE-ARI, unpubl. data).

Queensland

There are no priority actions specifically being implemented for Murray Cod in Queensland. Programs currently being delivered are directed towards broad issues such as improved fish passage and habitat rehabilitation.

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*.

Program Implementation

The national Murray Cod Taskforce (MCT), established under the Murray-Darling Basin Commission (MDBC) 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 Murray Cod Taskforce. The Murray Cod Recovery Team comprises representatives from each State and Territory agency responsible for threatened species. 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.

Subject to available resources, implementation of individual actions will remain the responsibility of the relevant agencies and organisations identified in the Recovery Plan, 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 priority actions, identify priority areas for implementation, and facilitate liaison between agencies where required.

The management of Murray Cod occurs across its range of almost 1 million km², involving both state and Commonwealth jurisdictions and their agencies and stakeholders. A concerted effort is underway to identify mutual interest and benefits from conservation agencies and recreational anglers working together. This process is building a cooperative approach amongst these groups that will undertake some of the actions outlined in this recovery plan. In particular, the need for a coordinated approach to recreational fishery management has been recognised and a sub-set of the recovery actions relating to fishery issues (mainly under Objective 5) have been discussed and updated in a forum conducted by state fisheries agencies and recreational angler representatives (DPI, Fisheries Victoria, 2010a). These include a commitment by fisheries agencies, researchers and angling organisations to a coordinated approach to research and management overseen by a multi jurisdictional group that will develop and implement a *Murray*

Cod Fishery Management Action Plan (DPI, Fisheries Victoria, 2010b). This action plan will be linked to the recovery plan and represents a basin-wide commitment to manage the Murray Cod recreational fishery within an adaptive management framework.

Proposed actions cover a range of methodologies including habitat management, research, survey, fisheries management, 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, NSW, ACT, Victoria and SA), at research centres including: the Arthur Rylah Institute for Environmental Research (Melbourne Vic), Narrandera Fisheries Centre (NSW), Murray-Darling Freshwater Research Centre (Mildura), 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, and fisheries management 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 funding opportunities 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.

Recovery Objectives

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

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

1. Determine the 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 on Murray Cod populations 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 their associated actions below align well with the priority objectives identified during the workshop Management of Murray Cod in the MDB (Lintermans and Phillips 2005), outlined in the associated document '*Background and Implementation Information for the Murray Cod Recovery Plan*'.

Recovery Actions

Table 3 below provides a summary of all actions are listed under each of the seven Objectives. These actions have been developed and reviewed at workshops of the Murray Cod Recovery Team and Murray Cod Taskforce. Additional details of these actions are given in the associated background document, including priority, timeframe, ease of achievement and agencies and organizations which may participate in implementation of actions. The suggested potential contributors' list outlined in the background document is indicative only and needs to be determined within each jurisdiction.

A total of 71 actions have been identified to address the range of threats and management issues identified within this recovery plan. These actions are necessarily broad i.e. not site-specific, given the broad species' range and wide ranging distribution of landscape scale threats. It is however recognised that these actions, where appropriate/relevant, should be targeted to protect and rehabilitate Important Populations and mitigate threats where Populations Under Threat have been identified. The identification of Spatial Management Units for Murray Cod should also facilitate implementation of actions for distinct areas.

Implementation of Highest Priority Actions

Of the 71 actions, 51 are considered a high priority (identified in bold within Table 3). It is recognized that while this is a large number of actions, many actions are required to improve the conservation status of this species. This list of actions represents a mix of actions that are not currently being addressed and require initiation, as well as actions which are already being addressed, both largely or partly, through existing programs in some or all of the relevant jurisdictions. In this context, there is great potential for Murray Cod to be a major beneficiary of many of these existing programs (see Management Practices section).

The 51 high priority actions were again revisited by the Murray Cod Taskforce, to identify those actions which should be the focus of most attention in the first five years of the implementation of this recovery plan. These were selected according to their:

- applicability and transferability across the basin
- feasibility
- ability to address key knowledge gaps which currently hamper effective management
- potential to enable measurable and achievable onground outputs
- flow-on effects to other actions.

From this revision, six key priority areas for immediate action for Murray Cod recovery were determined.

Priority Actions for Murray Cod Recovery

Population structure and management

Determine the distribution, structure and dynamics of Murray Cod populations across the MDB and devise appropriate Spatial Management Units and monitoring program (Especially actions 1.1, 1.3, 1.4, 1.14 and 5.6).

Recruitment

Identify and quantify the environmental parameters (e.g. flows and available food) that drive recruitment and population growth (Especially actions 1.12 and 2.1).

Habitat use, protection and repair

Identify, protect and repair key aquatic and riparian habitats for Murray Cod in each Spatial Management Unit (Especially actions 1.6 and 4.1).

Sustainable take

Manage the recreational fishery for Murray Cod in a sustainable manner while recognising the social, economic and recreational value of the fishery (Especially actions 5.1 and 5.6).

Community ownership

Encourage community awareness and support for Murray Cod management (including angling and conservation groups) (Especially actions 6.1, 6.4 and 5.5).

Recovery Plan implementation

Establish a long-term structure for the implementation of the national Murray Cod Recovery Plan (Action 7.1).

The effective implementation of the recovery plan requires a concerted effort to promote the objectives and actions and the successful implementation of management actions requires the involvement and commitment of a range of organisations. Undertaking extensive liaison with these agencies will be essential from an early stage to foster a sense of ownership and obligation of the actions needed to ensure the successful recovery of Murray Cod. Integration of management efforts and the monitoring of the response of Murray Cod to rehabilitation programs will maximise the cost savings by achieving multiple benefits. Community support for Murray Cod conservation is vital to ensuring the successful outcome of recovery efforts. Community group (especially angler) involvement in Murray Cod conservation and ensuring sustainable recreational fishing opportunities will be maintained and expanded. Opportunities include training specific Fishcare volunteers to have a focus on and promote Murray Cod conservation, 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 and the NFS coordinators and the MCT should play a role in implementing this action. These actions need to be undertaken in a coordinated manner through a recovery team with the support of a Murray Cod Recovery Plan national coordinator.

Recovery Objectives, Performance Criteria and Actions – Summary

(priority actions highlighted in **bold**)

Objective	Performance Criteria	Actions
1. Determine the distribution, structure and dynamics of Murray Cod populations across the MDB.	An improved understanding of distribution, abundance and population structure of Murray Cod across the MDB and incorporation of this information into NRM strategies and plans in the Basin.	<p>1.1 Review and synthesize published information on the population structure, status and dynamics of Murray Cod populations across the Basin.</p> <p>1.2 Identify gaps in distribution and population data and develop and implement a survey program to obtain data to address this.</p> <p>1.3 Determine the genetic composition of Murray Cod populations throughout the Basin.</p> <p>1.4 Identify appropriate Spatial Management Units for Murray Cod management (jurisdictional, habitat zones, genetic Management Units) across their range.</p> <p>1.5 Prioritise the Spatial Management Units that require urgent or specific management actions; monitor and maintain these units.</p> <p>1.6 Identify, protect and repair key aquatic and riparian habitats for Murray Cod in each Spatial Management Unit.</p> <p>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.</p> <p>1.8 Investigate the role and relationships of Murray Cod within the fish community.</p> <p>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.</p> <p>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.</p> <p>1.11 Identify key recruitment areas in each Spatial Management Unit.</p> <p>1.12 Identify and quantify the environmental parameters that drive recruitment and population growth, especially age-specific survivorships.</p> <p>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.</p> <p>1.14 Develop and implement an integrated, long-term monitoring program for assessing recovery of Murray Cod populations in each Spatial</p>

		Management Unit.
2. Manage river flows to enhance recruitment to Murray Cod populations.	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.	<p>2.1 Determine the influence of flows on critical life history components, especially recruitment of larvae and juveniles, and movement.</p> <p>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.</p> <p>2.3 Monitor population responses to prescribed flows and incorporate this knowledge into improved flow management practices.</p> <p>2.4 Develop and implement flow management practices to benefit recovery of Murray Cod populations.</p>
3. Undertake risk assessments of threats and evaluate benefits of recovery actions on Murray Cod populations for each Spatial Management Unit.	An improved understanding and management of the main threatening processes affecting Murray Cod populations across the MDB.	<p><i>Habitat Characteristics and Preferences</i></p> <p>3.1 Test the effects of habitat manipulations such as moving snags on Murray Cod.</p> <p>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.</p> <p><i>Fish Passage</i></p> <p>3.3 Identify barriers to movement of Murray Cod populations, particularly downstream.</p> <p>3.4 Facilitate fish passage for Murray Cod in both upstream and downstream directions.</p> <p>3.5 Monitor the response of Murray Cod populations to improved fish passage.</p> <p><i>Cold Water Population</i></p> <p>3.6 Quantify the impacts of cold water pollution on Murray Cod populations in each Spatial Management Unit.</p> <p>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.</p> <p>3.8 Determine, plan and implement a pilot site for remedial actions for cold water pollution for Murray Cod.</p> <p>3.9 Develop and implement a monitoring program to assess the response of Murray Cod to remedial actions for cold water pollution.</p> <p><i>Fish Kills</i></p> <p>3.10 Investigate the incidence, severity, causes of, and responses to fish kills involving Murray Cod.</p> <p>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.</p>

		<p>3.12 Establish a fish kills database and website to provide information on fish kills.</p> <p>3.13 Develop and implement consistent fish kill response protocols across the MDB and ensure appropriate linkages between agencies and knowledge sharing.</p> <p>3.14 Ensure that opportunities are taken to collect scientific data from fish kills.</p> <p>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.</p> <p><i>Irrigation Practices</i></p> <p>3.16 Quantify the loss of Murray Cod through irrigation systems and improve water diversion practices to reduce loss of fish.</p> <p><i>Recovery Management Options</i></p> <p>3.17 Investigate the feasibility, design and implementation of potential additional Murray Cod sustainable recovery management options.</p> <p>3.18 Establish a site to trial revised Murray Cod sustainable recovery management options, identified as necessary in Action 3.17.</p> <p>3.19 Determine the role and need for conservation stocking and/or translocation to restore or enhance identifiable local Murray Cod populations.</p> <p>3.20 Develop and apply a population model for Murray Cod to assess impacts of threats and recovery options.</p> <p><i>Governance Framework</i></p> <p>3.21 Establish a whole of government responsibility which defines agency roles, responsibilities and accountability for protecting Murray Cod populations in each jurisdiction.</p> <p>3.22 Encourage uptake of responsibilities and accountabilities for protecting Murray Cod populations and their habitats both within and between agencies and jurisdictions.</p>
4. Determine the habitat requirements of Murray Cod life stages and populations.	Predictive model for potential habitat developed and tested, and habitat preference information identified and incorporated in NRM plans in the MDB.	<p>4.1 Determine the habitat use by different life stages and populations of Murray Cod and identify key habitat conditions on which to focus management actions.</p> <p>4.2 Survey and map potential habitat, using ecological and bioclimatic information that may indicate the location of important habitat areas.</p> <p>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.</p> <p>4.4 Develop and implement management actions to protect structural habitats in floodplain channels.</p> <p>4.5 Identify and protect habitat areas critical to the survival of Murray Cod.</p>

		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).
5. Manage the recreational fishery for Murray Cod in a sustainable manner while recognising the social, economic and recreational value of the fishery.	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.	<p>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.</p> <p>5.2 Review existing and potential fishing regulations and modify where appropriate to ensure sustainable Murray Cod fisheries.</p> <p>5.3 Review the use and impacts of set-lines as a capture method for Murray Cod and modify regulations if necessary.</p> <p>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.</p> <p>5.5 Provide information to politicians, magistrates and the public on the community and conservation value of Murray Cod.</p> <p>5.6 Determine the contribution of stocking programs to Murray Cod populations and fishing catch.</p> <p>5.7 Investigate the impact of stocking hatchery-bred Murray Cod on wild populations.</p> <p>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.</p> <p>5.9 Investigate damage and mortality rates of angler captured and released Murray Cod.</p> <p>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.</p> <p>5.11 Implement the quality assurance measures for hatcheries outlined in 'Managing Fish Translocation and Stocking in the MDB' workshop (WWF 2003).</p>
6. Encourage community ownership for Murray Cod conservation.	There is broad community and partner understanding of, support for and participation in sustainable management of Murray Cod populations across the Basin.	<p>6.1 Promote Murray Cod as an icon species to raise awareness of river health and sustainability in the community.</p> <p>6.2 Document the significance of Murray Cod to the community, especially in Aboriginal culture and oral history, and for contemporary rural communities.</p> <p>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.</p>

		<p>6.4 Develop and implement a plan of community involvement (including anglers, angling clubs/associations and peak bodies and conservation groups) in the management and research of Murray Cod.</p> <p>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.</p>
7. Manage Recovery Plan implementation.	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.	<p>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 MCT.</p> <p>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</p> <p>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.</p> <p>7.4 Compile and transfer new knowledge and research results into an appropriate form for use by management agencies to develop management practices.</p> <p>7.5 Coordinate communication and exchange of information appropriate to the recovery program at National, State and regional levels.</p> <p>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.</p> <p>7.7 Ensure funding submissions are organised through appropriate management agencies each year (or as required).</p> <p>7.8 Establish a process for assessment (monitoring and evaluation) of Recovery Plan actions, including effective collation and dissemination of results.</p> <p>7.9 Undertake a formal review and evaluation at termination of this Recovery Plan.</p>

Implementation Costs

The estimated cost of high priority actions in the recovery program is \$24.4 million over five years. 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.

Summary of the estimated cost of high priority and other actions (costs 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

Integration with Existing Management and Research

The Murray Cod is a potential major beneficiary of a range of broad habitat-based rehabilitation programs across the MDB, such as facilitating fish passage, creation of new habitat through resnagging and restoring increased flows. In particular, efforts to restore ecological processes in the Murray River, including increased environmental flows in the Murray River and facilitating fish passage between the Murray mouth and Lake Hume (Albury) will benefit the species.

Communication and Integration

- A national Murray Cod Taskforce was established in 2004 to advise on issues affecting Murray Cod conservation and management.
- 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.

Broad-scale Rehabilitation Programs

- 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).
- The removal of redundant weirs in several locations in NSW and Vic is currently being investigated.
- 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 could consider recommendations of this report.
- 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.

Recreational Fishing

- 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).
- There are also a number of management measures including stocking and restrictions on angling that are undertaken to manage recreational angling. An Aboriginal 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.

Monitoring and Stock Assessments

- 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.
- Chowilla fish community study (SA).

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:

Objective 1 – Determine the distribution, structure and dynamics of Murray cod populations across the MDB

- Recruitment ecology of MD fish (Vic) (Action 1.9)
- Determining the role of anabranch channels on Murray Cod (Vic) (Action 1.6)
- Downstream movement of larval fish (NSW) (Action 1.7)
- Meso-scale movements of fish in the MDB (Qld) (Action 1.7)
- Use of fishways by Murray Cod, habitat use and feeding migrations (Qld) (Action 1.7)
- Murray Cod modelling to address key management options (Vic) (Action 1.12)
- DPI&F annual fish community monitoring surveys in Warrego and Paroo rivers (Qld) (Action 1.14).
- Genetic structure of wild populations and parentage assessment of a captive population Rourke 2007, (Rourke et al. 2009)

Objective 2 – Manage river flows to enhance recruitment to Murray cod populations

- Campaspe flow manipulation project (Vic) (Action 2.3)
- Assessing effectiveness of environmental flow allocations on native fish (Vic) (Action 2.3)

Objective 3 – Undertake risk assessments of threats and evaluate benefits of recovery actions on Murray cod populations for each management unit

Habitat Characteristics and Preferences

- River rehabilitation through resnagging (Vic) (Action 3.1)
- Fish Passage
- Murray River Fishways Assessment project (NSW, Vic, SA) (Action 3.5)
- Use of fishways by Murray cod (Qld) (Action 3.5)
- Effect of weirs on larval fish dispersal (NSW) (Action 3.3)
- Identify barriers to gene flow (Rourke 2007)
- Cold Water Pollution
- Assessing the effects of thermal pollution on native fish in the Mitta Mitta River (Vic) (Action 3.6)

Irrigation Practices

- Determining the use of off-channel habitats by native fish (Vic) (Action 3.16)
- Quantification of native fish loss in water supply offtakes (NSW) (Action 3.16)

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

- Determination of movement and habitat requirements of Murray Cod (Vic) (Action 4.1)
- Murray River fish surveys (Vic, NSW) (Action 4.1)

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

- Statewide recreational fishing diary program (Qld) (Action 5.1)
- 2007 review of Qld *Fisheries (Freshwater) Management Plan* 1999 (Qld) (Action 5.2, 5.3)
- Survival rates of stocked fish (Vic) (Action 5.6)
- Impacts of native fish stocking on fish within the MDB (Action 5.7)
- Stocking strategies for hatchery reared threatened fish (Qld) (Action 5.7)
- Sustaining recreational Murray Cod fisheries in MDB (Vic) (Action 5.10)
- Implementation of industry hatchery assurance protocols (Qld) (Action 5.10)
- Investigate the impact of stocking on genetic structure and diversity of wild populations (Rourke 2007)

Objective 6 – Encourage community ownership of Murray Cod conservation

- Annual freshwater fishing and stocking workshops (Qld) (Action 6.4)
- Statewide Fishcare volunteer program (Qld) (Action 6.4)
- Demonstration reach program (Qld) (Action 6.4)

While a range of management practices planned or underway may be of benefit, it needs to be recognised that there are 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 instream, or potential habitats, 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, reductions in flooding or unseasonally high flows.

- Releases from impoundments of poor quality water that is detrimental to fish populations downstream.
- Poor water quality as a result of decreased flows, increased nutrients, extraction etc.
- Removal of water from rivers (e.g. irrigation channels) without preventing loss of fish (including larvae) 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 catchment erosion, 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).
- Pesticide and fertiliser run-off, changing nutrient regimes leading to algal blooms, reduction in dissolved oxygen, increased sedimentation rates etc.
- Legal take and illegal take from key wild populations that alter population structures and threaten sustainability.

Funding of Recovery Actions

There are costs associated with implementation of this Recovery Plan, specifically acquiring the funding required to implement the actions. A considerable amount of funding is already available for environmental programs in the MDB, such as *The Living Murray* and *The Native Fish Strategy* programs. The monitoring of cod populations to assess their response to environmental restoration of rivers, such as through installation of fishways or increases in environmental flows, should be seen as integral to broader environmental restoration programs. However, when compared against the substantial funding for natural 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 sustainable future for this iconic species. Investment in Murray Cod should be seen as attractive given its potential use as an umbrella species.

The Plan includes actions to address the need to seek specific funding opportunities, as well as ensuring integration of Murray Cod recovery with major natural resource management 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 MDB 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. This has already been undertaken for Trout Cod in the Ovens River. The listed threatened communities 'Lowland riverine fish community of the southern MDB' 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 NSW 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 MDB, such as habitat degradation, barriers to migration and invasive species.

Affected Interests

The Murray Cod occurs in rivers and streams with a variety of managers and management tenures. Consequently, management is the responsibility of a range of agencies, organisations and individuals. The range of organisations with an interest in the species' conservation is provided in Appendix 1.

Role and Interests of Aboriginal People

The National Indigenous Technical Working Group (NIFTWG) recently identified a number of principles to guide the future development of Aboriginal fishing strategies (National Indigenous Fisheries Principles) which have been developed and endorsed by most States and Territories in Australia.

Murray Cod is an important cultural icon for Aboriginal tribes living adjacent to inland waters and traditionally was a major part of their diet (Ramsay Smith 1930; Lawrence 1971; Kearney and Kildea 2001). Aboriginal legend credits the creation of the wide, meandering Murray River and the other native fish in the system to *ponde* (Murray Cod: Rowland 1988a, 1989, 2005). The cod is a symbol of both the river's creation and degradation (Sinclair 2005). The species has totemic significance to the Aboriginal community (Phil Duncan, MDBC, pers. comm.).

In 2004, the MDBC hosted a meeting of Aboriginal nations from throughout the MDB to facilitate their involvement in natural resource management in the Basin. In recognition of the importance of Murray Cod to Aboriginal peoples of the Basin, the MDBC recently issued a contract to document the importance of Murray Cod to Aboriginal communities.

Aboriginal groups throughout the range of the Murray Cod have been identified by the recovery team members and the draft Recovery Plan will be sent to these groups for comment. Opportunities to involve Aboriginal groups in the implementation of this Recovery Plan will also be explored.

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). 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. Murray Cod

is a draw-card for tourism to the MDB, and giant cod replicas can be found in several towns in the region including Swan Hill (Vic) and Tocumwal (NSW). The species 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). Many Australians hold passionate views about Murray Cod, be they angler, scientist, riverside resident, environmentalist or water manager. This has been demonstrated recently through strong public reactions to fish kills in Victoria.

The Murray-Darling River system is already the focus of considerable management attention including improvements to flow regimes, provision of fish passage over barriers, and rehabilitation of riparian zones. Community involvement in these programs is facilitated through State NRM agencies, 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 social impacts of this Recovery Plan relate to issues concerning recreational angling. Murray Cod is a premier, highly sought after, freshwater angling species, and 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. The long-term decline in Murray Cod populations has deprived many rural communities of the social and recreational 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 MDB communities in these areas. 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 species' range over the long-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). 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. Many anglers now display a photograph of the fish they have captured and are justifiably proud to release the fish alive. The recent national survey also found that the primary motivation of 37% of fishers was 'to relax and unwind' and only 8% of fishers caught fish primarily for food.

Some actions will have a short-term social cost. This however needs to be balanced with the long-term goal of achieving sustainable populations, so that current access opportunities enjoyed by recreational anglers 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.

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). Changes to management practices that may alleviate cold water pollution and hence any existing cold water fisheries, or any additional protection measures for Murray Cod, will need to be subjected to extensive public consultation including with angling, aquaculture and tourism industry groups.

Managing public perceptions and expectations will be a major issue in implementing this Recovery Plan. 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 be due to 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). The observations and

documented data 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.

Two issues relevant to Murray Cod and this Recovery Plan evoke 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

Some groups consider the use of set-lines to catch Murray Cod an archaic anachronism that has nothing to do with the sport of recreational angling. Other groups however consider set-lines a long-used method of harvesting cod for food. The *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, which are permitted in some States.

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 Wildlife 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 and would require extensive consultation. Consideration of protected areas is one of many potential management options for Murray cod that could be considered under Action 3.17.

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 future amendments may be made to incorporate freshwater ecosystems.

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 SA, Victoria and NSW. Commercial fishing of wild Murray Cod in the MDB ceased in NSW in 2001, Victoria in 2002 and SA in 2003. The aquaculture industry for Murray Cod however in NSW and Victoria is rapidly expanding, with over 150 tonnes per year now produced for domestic and international markets (Ingram *et al.* 2005). In SA, Murray Cod is a permitted by-product species in the Lakes and Coorong Fishery, although there have been very low catches (<300kg) in the last five years.

Murray Cod is a premier, keenly sought after species by recreational anglers, but there are limited quantitative assessments of its recreational value. The recent National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003) provided valuable information, identifying 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), SA (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 144,222kg (93,973kg NSW, 27,469kg Vic and 22,780kg SA). It had previously been estimated that 140,000 fish weighing 220,000kg was captured in NSW 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 and communities 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 closed. In relation to recreational fishing, improvement in the species' status would lead to improvements in recreational fishing catch and increase economic benefits to some 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.

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Appendix 1. Organisations with an interest in Murray Cod conservation

Organisation	Type
<i>National/Regional</i>	
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
<i>Queensland</i>	
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
<i>New South Wales</i>	
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
Parks Victoria	State Government
Environment Protection Authority 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	
Australia New Guinea Fishes Association – SA	Community Group
Department for Environment and Natural Resources (SA)	State Government
Department of Primary Industries and Resources South Australia	State Government
Department of Water, Land and Biodiversity Conservation	State Government
Lakes and Coorong Fishers	Industry Group
Native Fish Australia	Community Group
River Murray Local Action Planning Groups	Community Groups
South Australian Field and Game Association	Community Group
South Australian Research and Development Institute	State Government
South Australian Recreational Fishing Advisory Council (SARFAC)	Industry Group
Southern Fishermen's Association	Industry Group
South Australia Murray-Darling Basin Natural Resource Management Board	Regional Authority

