

39. Murray Cod *Maccullochella peelii*

Qifeng Ye^a, Steven Brooks^b, Gavin Butler^c, Jamin Forbes^c, George Giatas^a, Dean Gilligan^e, Taylor Hunt^d, Peter Kind^b, John Koehn^d, Mark Lintermans^e, Andy Moore^d, Charles Todd^d and Brenton Zampatti^a



Table 1: Stock status determination for Murray Cod

Jurisdiction	South Australia	Victoria	New South Wales	Australian Capital Territory	Queensland
<i>Stock</i>	South Australia	Victoria	New South Wales	Australian Capital Territory	Queensland
<i>Stock status</i>					
	Undefined	Undefined	Undefined	Undefined	Undefined
<i>Indicators</i>	CPUE, age/size composition	CPUE, age/size composition	CPUE, age/size composition	CPUE, age/size composition	CPUE, age/size composition

CPUE = catch per unit effort

Stock structure

Murray Cod is the largest solely freshwater fish in Australia. It occurs throughout most of the Murray–Darling system, except for the upper reaches of some tributaries in Victoria and southern New South Wales. Investigation of the genetic structure of Murray Cod in the Murray–Darling Basin has demonstrated that, where there is connectivity between catchments, one large genetically panmictic biological stock exists throughout most of its distribution¹. However, genetically distinct populations have been identified in the Lachlan, Macquarie and Gwydir catchments¹. This separation appears to be the result of restricted gene flow due to wetland barriers, but may also be influenced by stocking programs¹.

Although genetic studies show evidence for one large biological stock, stock status of Murray Cod is reported at a jurisdictional level because of differences in management arrangements and available information.

Stock status

Murray Cod is the most socially, economically and culturally important freshwater fish species in the Murray–Darling Basin. It supports important recreational fisheries and is an important fish to Indigenous Australians^{2,3}. For example, anglers specifically targeting Murray Cod in Victoria alone contribute approximately \$59 million

a South Australian Research and Development Institute
b Department of Agriculture, Fisheries and Forestry, Queensland
c Department of Primary Industries, New South Wales
d Department of Environment and Primary Industries, Victoria
e Institute for Applied Ecology, University of Canberra
f Australian Bureau of Agricultural and Resource Economics and Sciences

per year to the economy and support an estimated 374 jobs²; this figure is expected to be much higher across the species' range. Commercial fishing for Murray Cod is currently prohibited in the Murray–Darling Basin.

Since European settlement, populations of Murray Cod have generally declined throughout its range as a result of a number of threats, including river regulation, habitat degradation, disease, and exploitation by commercial and recreational fishers^{4–7}. Take by recreational anglers has also been shown to affect population structure⁸. Consequently, Murray Cod is listed as 'Vulnerable' under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth). A national recovery plan has been developed for this species⁹. A cross-jurisdictional Murray Cod Fishery Management Group was established to improve collaboration on, and alignment of, recreational fisheries management and research for the species across the Basin¹⁰. Management strategies, including the closure of commercial fisheries, harvest restrictions, restocking, and seasonal closures to protect spawning populations, have resulted in recovery in some areas^{11–16}. However, there are still concerns for Murray Cod stocks across much of their range, and Basin-wide recovery may take decades.

South Australia

In South Australia, previous stock assessments for Murray Cod in the lower Murray River and Lower Lakes highlighted a significant decline in annual commercial landings, from 140 tonnes (t) in the late 1950s to less than 10 t in the 1970s and 1980s^{17,18}. Following a moratorium on commercial and recreational fishing, combined with high flows in the early 1990s, annual catch increased gradually to 28.5 t in 2001–02. The Murray Cod commercial fishery ceased in the South Australian lower Murray River in July 2003 following restructuring of inland native fisheries. Although Murray Cod is still a 'permitted species' to be taken in the commercial Lakes and Coorong Fishery, there is currently a temporary closure (implemented in 2010 under the *Fisheries Management Act 2007* (SA)) that prohibits Murray Cod from being harvested. Unlike some other jurisdictions, stocking practices have not been adopted in the South Australian lower Murray¹⁹.

In the absence of a commercial fishery, ongoing recreational fishery surveys or dedicated fishery-independent Murray Cod monitoring programs, the most recent assessment of the population dynamics of South Australian Murray Cod was conducted using data from three long-term (8–11-year) fish assemblage monitoring projects undertaken in the lower Murray River from 2002 to 2013²⁰. Catch per unit effort of electrofishing and drum netting indicates that Murray Cod relative abundance has remained reasonably constant over the past 8–11 years. Length-frequency distributions suggest that the majority of Murray Cod collected in the main channel habitats of the lower Murray River were large (more than 800 mm in length), and these fish represent a broad range of age classes (8–46 years). Murray Cod recruitment was minimal in the predominantly stillwater main channel habitats during the drought from 2001 to 2010. Nevertheless, some juvenile fish (less than 500 mm total length) were collected in main channel habitats in years following increases in water flow (for example, 2010–11). Consistent recruitment was evident in the flowing water habitats of the Chowilla anabranch system during the same period (2002 to 2013). Construction and operation of a regulator on Chowilla Creek may modify the hydraulic characteristics of the anabranch system and presents a risk to Murray Cod recruitment in this important area²¹. Despite these data, insufficient information is available to confidently classify the biomass of Murray Cod in the South Australian reaches of the Murray River.

The most recent South Australian Recreational Fishing Survey, in 2007–08, estimated that 507 Murray Cod (around 2.1 t) were harvested from the lower Murray River²². No Murray Cod were reported as caught in the Lower Lakes region. There was little change in the total number of fish caught since the 2000–01 survey²³, but release rates have increased from 16 per cent in 2000–01 to 73 per cent in 2007–08. The 2007–08 figures should be considered only as indicative because the precision levels of all estimates were low (for example, numbers \pm 971) as a result of low numbers of participants reporting Murray Cod catch, as well as low numbers of Murray Cod harvested. There was a moratorium on recreational fishing for this species in 2009 and 2010 in South Australia. Since 2011, a catch-and-release fishery has been permitted for Murray Cod in the South Australian Murray River, except for a closure area in Chowilla. However, uncertainty remains about the level of fishing effort and overall post-release mortality associated with the catch-and-release fishery. The above evidence indicates that insufficient information is available to confidently classify the fishing pressure on Murray Cod.

Because of the uncertainty regarding mortality and biomass, insufficient information is available to confidently classify the status of this stock.

On the basis of the evidence provided above, Murray Cod in South Australia is classified as an **undefined stock**.

Victoria

In Victoria, Murray Cod numbers are currently much lower than pre-European levels. During the 19th century Murray Cod populations were considered abundant in the Loddon, Campaspe and Goulburn rivers²⁴. However, by the middle of the 20th century, these populations of Murray Cod had declined in these rivers²⁵. Commercial catch rates continued to decline across the Murray–Darling Basin, including in Victoria, in the 1960s. In Victoria, commercial catches of Murray Cod were highest between 1954–55 and 1960–61, at approximately 10–15 t per year; catches were approximately 1.5 t per year on average in the next 10 years and negligible thereafter²⁶. No estimates of catch per unit effort have been recorded for Victoria; consequently, it is difficult to compare Victorian commercial catch data through time.

Hatchery-produced Murray Cod have been stocked in Victoria since 1981. In 2013, approximately 600 000 Murray Cod were stocked into 29 waters across Victoria. Other surveys, such as the Murray–Darling Basin Authority Sustainable Rivers Audit¹², indicate fish biomass to have increased in some catchments (Ovens, Goulburn and Loddon rivers) and declined in others (Broken and Kiewa rivers)¹³. In the absence of current statewide recreational fishing survey data, insufficient information is available to confidently classify the biomass of Murray Cod.

The last statewide estimate of recreational catch of Murray Cod in Victoria was measured as part of the National Recreational and Indigenous Fishing Survey²³. The 2000–01 survey estimated that 11 943 Murray Cod were harvested by Victorian anglers, equating to 27 469 kg of biomass. Between 2006 and 2008, recreational fishing creel surveys have been conducted on selected river reaches in Victoria, including the Goulburn, Ovens, Loddon and Murray rivers²⁷. Total Murray Cod catch within these river reaches was estimated at more than 98 000 fish, of which just over 6500 were harvested. Release rate for Murray Cod was around 90 per cent overall, with most releases being compulsory because the fish were smaller than the legal minimum length. Voluntary release rates of 14–32 per cent of fish larger than the minimum size limit were observed in the Goulburn and Murray rivers. The above evidence indicates that insufficient information is available to confidently classify the fishing pressure on Murray Cod.

On the basis of the evidence provided above, Murray Cod in Victoria is classified as an **undefined stock**.

New South Wales

In New South Wales, Murray Cod numbers are generally considered to be much lower than pre-European levels. Concerns were raised as early as 1880 about declines in the abundance of Murray Cod in New South Wales, based largely on falling catch rates in the commercial fishery⁷. The commercial fishery for Murray Cod was established throughout the lower Murray–Darling Basin in New South Wales in the mid-1800s. Catch rates declined dramatically from a high in the mid-1950s of around 140 t to less than 35 t by the mid-1960s, while fishing effort remained at around the same level⁷. The annual catch remained below 35 t in all years but 1974–75 until the fishery was closed in New South Wales in 2001.

Anecdotal reports and scientific surveys¹¹ suggest that there has been an increase in the abundance of Murray Cod in some New South Wales rivers²⁸. These include the Murrumbidgee River and many of the rivers in the Border Rivers region in the far north of the state.

As part of the recovery process in New South Wales, hatchery-reared Murray Cod have been stocked extensively in many of the impoundments and rivers throughout the state. It is estimated that 5 million fry and fingerlings have been produced and released since the program commenced in the early 1980s²⁸. Until recently, little was known of the success of these stockings, and it was largely assumed that stocking was a primary contributor to the recovery of the species in some systems. As part of the New South Wales Effectiveness of Stocking program, an assessment of Murray Cod stocks was undertaken in two rivers in the southern Murray–Darling Basin and one impoundment in north-western New South Wales²⁹. A comparatively low proportion of stocked Murray Cod was caught in the Murray River (7 per cent) and Murrumbidgee River (15 per cent), which could suggest that these populations are primarily self-supporting through natural recruitment²⁸. In contrast, stocked Murray Cod comprised almost the entire population (94 per cent) within Copeton Dam²⁸. These data suggest that, although stocking is helping with the recovery of Murray Cod in New South Wales, other management actions such as closed seasons, size-and-bag regulations and habitat rehabilitation are also contributing. The above evidence indicates that insufficient information is available to confidently classify the biomass of Murray Cod.

Although there is now no commercial fishery for Murray Cod in New South Wales, the recreational fishery for this species has continued to grow. The 2000–01 national survey estimated that, at that time, about 483 000 Murray Cod were caught annually by recreational anglers throughout south-eastern Australia, with around 78 per cent of these fish released²³. A more recent survey undertaken in 2012–13 across 76 km of the Murrumbidgee River estimated annual catch of Murray Cod within the reach to be as high as 32 000, with only 5 per cent of these retained²⁹. These results suggest that targeting of the species by the recreational sector remains high, and that the practice of catch and release may be increasing. The above evidence indicates that insufficient information is available to confidently classify the fishing pressure on Murray Cod.

On the basis of the evidence provided above, Murray Cod in New South Wales is classified as an **undefined stock**.

Australian Capital Territory

In the Australian Capital Territory, Murray Cod numbers are generally considered to be much lower than pre-European levels. Anecdotal evidence noted that the species had declined considerably before 1980³⁰. Murray Cod is stocked in a number of urban lakes to provide recreational fishing opportunities, as well as to provide an apex predator for these artificial systems³¹. Approximately 690 000 Murray Cod fingerlings have been stocked since the program began in 1981³¹, with approximately 20 000–30 000 stocked annually. Stocking of native fish for recreational purposes is not conducted in riverine environments, and there have been no conservation stockings of the species³¹. Murray Cod have never been commercially harvested in the Australian Capital Territory, but have long been a popular recreational target both in the Murrumbidgee and Molonglo rivers and in the urban lakes. An angler survey in 1999–2001 of the Murrumbidgee River in the Australian Capital Territory identified that Murray Cod were the equal highest species targeted (along with Golden Perch)³². The National Recreational and Indigenous Fishing Survey²³ did not report Murray Cod harvest data for the Australian Capital Territory. However, data from associated sampling, although sparse, indicate that only 25 per cent of Murray Cod were retained and that a higher proportion of retained fish (40 per cent) were captured from rivers than from dams. Stocked populations in urban lakes continue to provide localised, but well-regarded, recreational fisheries. However, the absence of regular or consistent creel or angler surveys on either the urban lakes or the Murrumbidgee River means that insufficient information is available to confidently classify the fishing pressure on Murray Cod.

Because the majority of ecological knowledge of Murray Cod has been derived from studies in lowland habitats^{33–35}, and there is little knowledge of Murray Cod ecology in upland regions, management arrangements and regulations for Murray Cod in the Australian Capital Territory have largely mirrored those in force in surrounding New South Wales. This arrangement has also minimised confusion for cross-border anglers. A recent 3-year study into the recruitment ecology of Murray Cod in the upper Murrumbidgee River revealed that spawning occurs at similar times to that recorded in lowland environments, with peak larval drift usually occurring in mid-November.

No obvious change in abundance of riverine populations of Murray Cod in the Australian Capital Territory has been seen since the 1980s. A standardised biennial fish monitoring program in the Murrumbidgee River in the Australian Capital Territory from 1994 to 2008 revealed little change in cod abundance, but sampling techniques (net based) were not particularly appropriate for sampling Murray Cod (unpublished data from the ACT Government). Subsequent monitoring has employed boat electrofishing, with higher numbers of cod captured. The above evidence indicates that insufficient information is available to confidently classify the biomass of Murray Cod.

On the basis of the evidence provided above, Murray Cod in the Australian Capital Territory is classified as an **undefined stock**.

Queensland

It is generally accepted that native fish populations in the Murray–Darling Basin's rivers have declined to an estimated 10 per cent of the levels before European settlement⁶; this is partially supported by anecdotal evidence provided by anglers in Queensland³⁶. The decline has resulted from flow regulation, habitat degradation, reduced water quality, barriers to movement, introduced species and overexploitation from illegal fishing⁶. The recent Murray–Darling Basin Authority Sustainable Rivers Audit and anecdotal evidence from recreational anglers suggest an increase in Murray Cod numbers in the Border Rivers region, which may be attributed to the extensive stocking in this catchment³⁷. The audit and other fishery-independent monitoring have been undertaken in several other rivers and catchments in Queensland^{6,36}. However, the lack

of consistency in sampling methodologies and the low numbers of Murray Cod recorded during the monitoring provided insufficient data to estimate biomass of Murray Cod in Queensland. Targeted monitoring is required to determine the current biomass of Murray Cod stocks in Queensland.

Approximately 100 000 Murray Cod have been stocked each year throughout their range in Queensland since the inception of the Recreational Fishing Enhancement Program in the mid-1980s. A large proportion of these fingerlings are stocked into impounded areas, where the levels of natural recruitment are low. The Queensland area of the Murray–Darling Basin has never supported a commercial fishery for this species. The above evidence indicates that insufficient information is available to confidently classify the biomass of Murray Cod.

Murray Cod support a considerable recreational fishery throughout the northern Murray–Darling catchment in Queensland. The species is mostly targeted within the Dumaresq, Macintyre, Moonie, Condamine, Balonne and Warrego rivers and their tributaries; fish are also occasionally reported from the Paroo River^{36,38}. A survey of recreational participation and catch was conducted in 2010³⁸. Unfortunately, little catch data for Murray Cod were collected during the survey, and any estimates of harvest for Murray Cod are unreliable and not informative. Data from a more recent study in the Border Rivers region suggest that harvest of Murray Cod remains high, with most fish being removed from the population within a couple of years of reaching legal size³⁷. Insufficient information is available to confidently determine the overall fishing mortality of the Murray Cod stock in Queensland, and further research is required to acquire this information. The above evidence indicates that insufficient information is available to confidently classify the fishing pressure on Murray Cod.

On the basis of the evidence provided above, Murray Cod in Queensland is classified as an **undefined stock**.

Table 2: Murray Cod biology^{34,39–44}

<i>Longevity and maximum size</i>	At least 48 years; ~1800 mm TL, 83 kg
<i>Maturity (50%)</i>	First maturity at ~4–5 years; ~450–600 mm TL for both sexes Variable across geographic regions

TL = total length

Figure 1: Distribution of Murray Cod based on reported catch in the Murray–Darling Basin, Australia, 2006 to 2013 (calendar years)

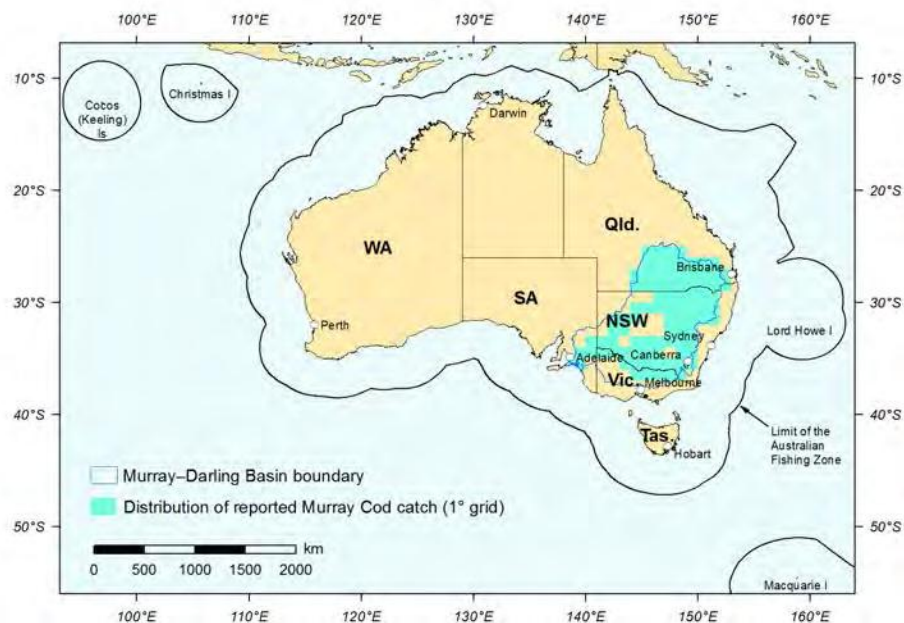


Table 3: Main features and statistics for Murray Cod in Australia, 2013 (calendar year)

Jurisdiction	South Australia	Victoria	New South Wales	Australian Capital Territory	Queensland
Fishing methods					
Commercial					
	None	None	None	None	None
Recreational					
Rod and line	✓	✓	✓	✓	✓
Hand line	✓	✓	✓	✓	✓
Indigenous					
Rod and line	✓	✓	✓	✓	✓
Hand line	✓	✓	✓	✓	✓
Traditional gear (e.g. spears, nets, traps)	✓	✓	✓		✓
Management methods					
Commercial^a					
	n/a	n/a	n/a	n/a	n/a
Recreational					
Bag limits	✓	✓	✓	✓	✓
Size limits		✓	✓	✓	✓
Seasonal closures	✓	✓	✓	✓	✓
Area closures	✓			✓	✓
Indigenous^{b,c}					
Bag limits	✓	✓	✓	✓	✓
Size limits	✓	✓	✓	✓	✓
Catch					
Commercial	None	None	None	None	None
Recreational	Unknown	Unknown	Unknown	Unknown	Unknown
Indigenous	Unknown	Unknown	Unknown	Unknown	Unknown

Jurisdiction	South Australia	Victoria	New South Wales	Australian Capital Territory	Queensland
Markets					
Domestic					
Export					

n/a = not applicable

a Murray Cod captured by the Lakes and Coorong Fishery are currently protected under South Australian fishing regulations.

b Indigenous fishers who can satisfy the requirements of the *Native Title Act 1993* (Cth) in relation to their connection to the specific area or waters may take sufficient Murray Cod to satisfy their customary, noncommercial domestic needs in South Australia and Queensland. Indigenous fishers who do not satisfy these requirements are subject to the standard recreational bag limits, size limits and closures.

c In Victoria, regulations for managing recreational fishing are also applied to fishing activities by Indigenous people. Recognised Traditional Owners (groups that hold native title or have agreements under the *Traditional Owner Settlement Act 2010* (Vic)) can apply for permits under the *Fisheries Act 1995* (Vic) that authorise customary fishing (for example, different catch and size limits, or equipment). The Indigenous category in Table 3 refers to customary fishing undertaken by recognised Traditional Owners. In 2012–13, there were no applications for customary fishing permits to access Murray Cod.

Effects of fishing on the freshwater environment

- Although Murray Cod is no longer targeted by commercial fishing, it is a highly prized catch for recreational anglers. Release rates are very high for this species because of catch-and-release practices or specific fishing regulations²³, which differ considerably between jurisdictions. Studies have investigated the post-release mortality of Murray Cod and found it to be between 2 and 15 per cent^{45,46}. In some cases, post-release mortality may contribute at least as much to fishing mortality of Murray Cod as harvest⁴⁵.
- Recreational fishers targeting Murray Cod often make incidental catches of other native species, such as Trout Cod and Golden Perch. The recreational catch of these other species is also controlled under state and territory recreational fishing regulations, but there may be post-release mortalities for these species. In general, recreational fishing for Murray Cod is thought to have minimal impact on the freshwater environment¹. Implications of disease and other potential environmental risks also need to be considered¹⁹. In addition, use of live organisms as bait is considered risky because of its potential to introduce and spread disease or noxious species, and the negative impacts that this may have on ecosystems⁴⁷.

Environmental effects on Murray Cod

- Like many freshwater fish in the Murray–Darling Basin, Murray Cod populations have declined since the early 1900s as a result of anthropogenic impacts, such as altered natural flow regimes, habitat loss, barriers to movement, cold-water releases from dams, interactions with alien species and overharvesting⁵. Murray Cod prefer structurally complex habitats (for example, coarse wood and overhanging vegetation) in the main channel of the river and anabranches^{48,49}. Habitat alteration, such as removal of snags from the main channel and anabranches, will decrease habitat availability and potentially reduce Murray Cod abundance. In addition, fast-flowing lotic habitats are considered to be important for survival of Murray Cod larvae, and as a habitat for juveniles and adults²⁰. Alteration to these conditions through anthropogenic (river regulation and water extraction) or natural (floods and drought) factors are likely to affect stocks.
- Enhanced recruitment of Murray Cod in lowland areas has been linked to increased river flow or flooding^{18,34}. The exact mechanism behind recruitment is unknown, but it is likely to be linked to an increase in food resources for larvae and juveniles following floodplain inundation³⁴.
- In lowland rivers, Murray Cod can undertake small- to large-scale movements (greater than 100 km) within the main river channel and anabranches, and between these habitats^{50,51}. Lateral and longitudinal

disconnection (for example, by structures or reduced flow) will alter the movement patterns of the species. In upland rivers, movements are likely to be limited by natural barriers such as gorges and waterfalls.

- Cold-water pollution due to low-level releases from dams has been deemed responsible for the loss of Murray Cod populations downstream of a number of impoundments^{52,53}. Anoxic blackwater events in lowland environments that may occur as a result of flooding after prolonged periods of low flow, and other poor water quality events, can result in considerable mortality of Murray Cod^{51,54}.

References

1. Rourke, ML, McPartlan, HC, Ingram, BA & Taylor, AC 2011, Variable stocking effect and endemic population genetic structure in Murray cod *Maccullochella peelii*, *Journal of Fish Biology*, 79: 155–177.
2. Ernst and Young 2011, Economic contribution of recreational fishing in the Murray–Darling Basin, Victorian Department of Primary Industries, Melbourne.
3. Lintermans, M 2007, *Fishes of the Murray–Darling Basin: an introductory guide*, Murray–Darling Basin Authority, Canberra.
4. Koehn, J 2005, Threats to Murray cod, in M Lintermans & B Phillips (eds), *Management of Murray cod in the Murray–Darling Basin: statement, recommendations and supporting papers, proceedings of a workshop held in Canberra, 3–4 June 2003*, Murray–Darling Basin Commission, Canberra.
5. Lintermans, M & Phillips, B 2005, *Management of Murray cod in the Murray–Darling Basin: statement, recommendations and supporting papers, proceedings of a workshop held in Canberra, 3–4 June 2003*, Murray–Darling Basin Commission, Canberra.
6. Murray–Darling Basin Commission 2004, *Native fish strategy for the Murray–Darling Basin 2003–2013*, publication 25/04, MDBC, Canberra.
7. Rowland, SJ 1989, Aspects of the history and fishery of the Murray cod, *Maccullochella peelii* (Mitchell) (Perciththyidae), *Proceedings of the Linnean Society of New South Wales*, 111: 201–213.
8. Nicol, S, Todd, C, Koehn, J & Lieschke, J 2004, How can recreational angling regulations help meet the multiple objectives for the management of Murray Cod populations?, in M Lintermans & B Phillips (eds), *Management of Murray cod in the Murray–Darling Basin: statement, recommendations and supporting papers, proceedings of a workshop held in Canberra, 3–4 June 2003*, Murray–Darling Basin Commission, Canberra.
9. National Murray Cod Recovery Team 2010, *National Murray Cod Recovery Plan for the Murray Cod Maccullochella peelii peelii*, Victorian Government Department of Sustainability and Environment, Melbourne.
10. Murray Cod Fishery Management Group 2012, *Communications plan 2011–2013*, Victorian Department of Primary Industries, Melbourne.
11. Barwick, MJ, Koehn, JD, Crook, DA, Todd, CR, Westaway, C & Trueman, W 2014, The future for managing recreational fisheries in the Murray–Darling Basin, *Ecological Management & Restoration*, 15: 75–81.
12. Davies, PE, Harris, JH, Hillman, TJ & Walker, KF 2008, *Sustainable Rivers Audit Report 1: a Report on the ecological health of rivers in the Murray–Darling Basin, 2004–2007*, prepared by the Independent Sustainable Rivers Audit Group for the Murray–Darling Basin Ministerial Council, Murray–Darling Basin Commission, Canberra.
13. Davies, PE, Stewardson, MJ, Hillman, TJ, Roberts, JR & Thoms, MC 2012, *Sustainable Rivers Audit 2: the ecological health of rivers in the Murray–Darling Basin at the end of the Millennium Drought (2008–2010), volume 1*, prepared by the Independent Sustainable Rivers Audit Group for the Murray–Darling Basin, Murray–Darling Basin Authority, Canberra.
14. Gilligan, D, New South Wales Department of Primary Industries, unpublished data, cited in Rowland, SJ 2013, Hatchery production for conservation and stock enhancement: the case of Australian freshwater fish, in G Allan & G Burnell (eds), *Advances in aquaculture hatchery technology*, Woodhead Publishing, Cambridge, England.
15. Harris, J & Gehrke P 1997, *Fish and rivers in stress: the NSW rivers survey*, New South Wales Fisheries Office of Conservation & Cooperative Research Centre for Freshwater Ecology, in association with New South Wales Resource and Conservation Assessment Council, Cronulla.
16. Lintermans, M, Rowland, SJ, Koehn, JD, Butler, GL, Simpson, B & Wooden, I 2005, The status, threats and management of freshwater cod species *Maccullochella* spp. in Australia, in M Lintermans & B Phillips (eds), *Management of Murray cod in the Murray–Darling Basin: statement, recommendations and supporting papers, proceedings of a workshop held in Canberra, 3–4 June 2003*, Murray–Darling Basin Commission, Canberra.
17. Ye, Q, Jones, K & Pierce, B 2000, *Murray cod (Maccullochella peelii peelii)*, Fishery assessment report to Primary Industries and Resources South Australia for the Inland Waters Fishery Management Committee, South Australian fisheries assessment series 2000/17, South Australian REsearch and Development Institute, Adelaide.

18. Ye, Q & Zampatti, B 2007, Murray cod stock status: the Lower River Murray, South Australia, Stock status report to Primary Industries and Resources South Australia (Fisheries), South Australian Research and Development Institute (Aquatic Sciences) publication F2007-000211-1, SARDI research series 208, SARDI, Adelaide.
19. Gillanders, BM & Ye, Q 2011, Ecological risk assessment of stocking Murray Cod in South Australia, report to Primary Industries and Resources South Australia (Fisheries and Aquaculture), School of Earth and Environmental Sciences, University of Adelaide, & South Australian Research and Development Institute (Aquatic Sciences), SARDI publication F2011/000299-1, SARDI research report series 571, SARDI, Adelaide.
20. Zampatti, BP, Bice, CM, Wilson, PJ & Ye, Q 2014, Population dynamics of Murray Cod (*Maccullochella peelii*) in the South Australian reaches of the River Murray: a synthesis of data from 2002–2013, report to Primary Industries and Regions South Australia (Fisheries and Aquaculture), South Australian Research and Development Institute (Aquatic Sciences) publication F2014/000089-1, SARDI research series 761, SARDI, Adelaide.
21. Mallen-Cooper, M, Zampatti, BP, Hillman, T, King, A, Koehn, J, Saddler, S, Sharpe, S & Stuart, I 2011, Managing the Chowilla Creek environmental regulator for fish species at risk, report prepared for the South Australian Murray–Darling Basin Natural Resources Management Board.
22. Jones, K 2009, South Australian Recreational Fishing Survey 2007/08, South Australian fisheries management series 54, Primary Industries and Resources South Australia, Adelaide.
23. Henry, GW & Lyle, JM 2003, The National Recreational and Indigenous Fishing Survey, Fisheries Research and Development Corporation project 00/158, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra.
24. Wilson, E 1857, On the Murray River Cod, with particulars of experiments instituted for introducing this fish into the River Yarra-Yarra, Transactions of the Philosophical Institute of Victoria, 2: 23–34.
25. Cadwallader, PL 1977, JO Langtry's 1949–50 Murray River investigations, Fisheries and Wildlife Paper, Victoria, 13: 1–70.
26. Ingram, BA & De Silva, SS 2004, Development of intensive commercial aquaculture production technology for Murray Cod, Primary Industries Research Victoria, Marine and Freshwater Systems, Department of Primary Industries, Queenscliff, Victoria.
27. Fulton, W 2011, Sustainability of recreational fisheries for Murray Cod in the Murray–Darling Basin, final report to the Fisheries Research and Development Corporation, project 2006/053, Victorian Department of Primary Industries, Queenscliff.
28. Rowland, SJ 2013, Hatchery production for conservation and stock enhancement: the case of Australian freshwater fish, in G Allan & G Burnell (eds), Advances in aquaculture hatchery technology, Woodhead Publishing, Cambridge, England.
29. Jamin Forbes, New South Wales Department of Primary Industries, unpublished data.
30. Greenham, P 1981, Murrumbidgee River aquatic ecology study, report to the National Capital Development Commission and the Department of Territories and Local Government, Canberra College of Advanced Education, Canberra.
31. Australian Capital Territory Government 2009, Fish stocking plan for the Australian Capital Territory 2009–2014, Department of Environment, Climate Change, Energy and Water, Canberra.
32. McGovern, A & Lintermans, M 2003, A creel survey of fish in the Murrumbidgee River, Australian Capital Territory, final report to Fisheries Action Program, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra.
33. Humphries, P 2005, Spawning time and early life history of Murray cod, *Maccullochella peelii* (Mitchell) in an Australian river, Environmental Biology of Fishes, 72: 393–407.
34. King, AJ, Tonkin, Z & Mahoney, J 2009, Environmental flow enhances native fish spawning and recruitment in the Murray River, Australia, River Research and Applications, 25: 1205–1218.
35. Rowland, SJ 1998, Aspects of the reproductive biology of Murray Cod, *Maccullochella peelii peelii*, Proceedings of the Linnean Society of New South Wales, 120: 147–162.
36. Steven Brooks, Queensland Department of Agriculture, Fisheries and Forestry, personal communication.
37. Gavin Butler, Steven Brooks & Daniel Smith, New South Wales Department of Primary Industries, & Queensland Department of Agriculture, Fisheries and Forestry, unpublished data.
38. Taylor, S, Webley, J & McInnes, K 2010, Statewide Recreational Fishing Survey, Queensland Department of Agriculture, Fisheries and Forestry, Brisbane.
39. Anderson, JR, Morison, AK & Ray, DJ 1992, Age and growth of Murray Cod, *Maccullochella peelii* (Perciformes: Percichthyidae), in the lower Murray–Darling Basin, from thin-sectioned otoliths, Australian Journal of Marine and Freshwater Research, 43: 983–1013.

40. Gooley, GJ, Anderson, TA & Appleford, P 1995, Aspects of the reproductive cycle and gonadal development of Murray Cod, *Maccullochella peelii peelii* (Michell) (Percichthyidae), in Lake Charlegrark and adjacent farm ponds, Victoria, Australia, *Marine & Freshwater Research*, 46: 723–728.
41. Lake, JS 1967, Principal fishes of the Murray–Darling River system, in AH Weatherley (ed.), *Australian inland waters and their fauna: eleven studies*, Australian National University, Canberra.
42. Rowland, SJ 1985, Aspects of the biology and artificial breeding of the Murray Cod, *Maccullochella peelii* and the Eastern Freshwater Cod *M. ikei* sp. nov. (Pisces: Percichthyidae), PhD Thesis, Macquarie University, Sydney.
43. Rowland, SJ 1998, Age and growth of the Australian freshwater fish Murray Cod, *Maccullochella peelii peelii*, *Proceedings of the Linnean Society of New South Wales*, 120: 163–179.
44. Whitley, GP 1955, The largest (and the smallest) Australian fishes, *Australian Museum Magazine*, 11: 329–332.
45. Douglas, J, Brown, P, Hunt, T, Rogers, M & Allen, M 2010, Evaluating relative impacts of recreational harvest and discard mortality on Murray Cod (*Maccullochella peelii peelii*), *Fisheries Research*, 106: 18–21.
46. Hall, K, Broadhurst, MK & Butcher, PA 2012, Post-release mortality of angled Golden Perch *Macquaria ambigua* and Murray Cod *Maccullochella peelii*, *Fisheries Management and Ecology*, 19: 10–21.
47. Phillips, B 2003, Managing fish translocation and stocking in the Murray–Darling Basin, workshop held in Canberra, 25–26 September 2002: statement, recommendations and supporting papers, World Wildlife Fund, Sydney.
48. Boys, CA & Thoms, MC 2006, A large-scale, hierarchical approach for assessing habitat associations of fish assemblages in large dryland rivers, *Hydrobiologia*, 572: 11–31.
49. Koehn, JD 2009, Multi-scale habitat selection by Murray Cod (*Maccullochella peelii peelii*) in two lowland rivers, *Journal of Fish Biology*, 75: 113–129.
50. Koehn, JD, McKenzie, JA, O’Mahony, DJ, Nicol, SJ, O’Connor, JP & O’Connor, WG 2009, Movements of Murray Cod (*Maccullochella peelii peelii*) in a large Australian lowland river, *Ecology of Freshwater Fish*, 18: 594–602.
51. Leigh, SJ & Zampatti, BP 2013, Movement and mortality of Murray Cod (*Maccullochella peelii*) during overbank flows in the lower River Murray, Australia, *Australian Journal of Zoology*, 61: 160–169.
52. Sherman, B, Todd, CR, Koehn, JD & Ryan, T 2007, Modelling the impact and its potential mitigation of cold water pollution on Murray Cod populations downstream of Hume Dam, Australia, *Rivers Research and Applications*, 23: 377–389.
53. Todd, CR, Ryan, T, Nicol, SJ & Bearlin, AR 2005, The impact of cold water releases on the critical period of post-spawning survival and its implications for Murray cod (*Maccullochella peelii peelii*): a case study of the Mitta Mitta River, southeastern Australia, *River Research and Applications*, 21: 1035–1052.
54. Koehn, J 2005, The loss of valuable Murray Cod in fish kills: a science and management perspective, in M Lintermans & B Phillips (eds), *Management of Murray Cod in the Murray–Darling Basin: statement, recommendations and supporting papers, proceedings of a workshop held in Canberra, 3–4 June 2003*, Murray–Darling Basin Commission, Canberra.